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APPLYING FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS AND HUMAN RELIABILITY ANALYSIS TECHNIQUES TO IMPROVE SAFETY DESIGN OF WORK PROCESS IN SINGAPORE ARMED FORCES

by

Weihao K. Soon
September 2016

Thesis Advisor:	Karen Holness
Second Reader:	Lawrence G. Shattuck

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The Singapore Armed Forces (SAF) has an instituted safety program that utilizes a generic risk assessment technique called the Risk Assessment Worksheet (RAW), which has several shortcomings. They include vague categorization to guide task decomposition, a generic 5-M factor hazard identification method, and insufficient resolution to prioritize risks. This thesis studies two alternative risk assessment techniques: Process Failure Modes, Effects, and Criticality Analysis (PFMECA) and Human Error Assessment and Reduction Technique (HEART), to determine their suitability for use by SAF. To compare the three techniques in assessing the risks associated with a specific work process, this thesis uses the activity of replacing the track on one side of an armored fighting vehicle in the workshop. Both PFMECA and HEART analyses were more effective than RAW. In addition, PFMECA and HEART were equally effective at identifying the top risks, as shown through side-by-side comparison and a case study. Furthermore, SAF personnel can easily learn and apply the PFMECA technique because SAF is already using a similar technique, the FMECA technique, for technical system analysis.

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Weihao K. Soon
Captain, Singapore Army
B.S., National University of Singapore, 2009

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Approved by: Karen Holness, PhD
Thesis Advisor

Lawrence G. Shattuck, PhD
Second Reader

Ronald E. Giachetti, PhD
Chair, Department of Systems Engineering

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ABSTRACT

The Singapore Armed Forces (SAF) has an instituted safety program that utilizes a generic risk assessment technique called the Risk Assessment Worksheet (RAW), which has several shortcomings. They include vague categorization to guide task decomposition, a generic 5-M factor hazard identification method, and insufficient resolution to prioritize risks. This thesis studies two alternative risk assessment techniques: Process Failure Modes, Effects, and Criticality Analysis (PFMECA) and Human Error Assessment and Reduction Technique (HEART), to determine their suitability for use by SAF. To compare the three techniques in assessing the risks associated with a specific work process, this thesis uses the activity of replacing the track on one side of an armored fighting vehicle in the workshop. Both PFMECA and HEART analyses were more effective than RAW. In addition, PFMECA and HEART were equally effective at identifying the top risks, as shown through side-by-side comparison and a case study. Furthermore, SAF personnel can easily learn and apply the PFMECA technique because SAF is already using a similar technique, the FMECA technique, for technical system analysis.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASEP	accident sequence evaluation program
EPC	error producing conditions
FFBD	functional flow block diagram
FMEA	failure modes effects analysis
FMECA	failure modes, effects and criticality analysis
HAZOP	hazard and operability
HEART	human error assessment and reduction technique
HEP	human error probability
HRA	human reliability analysis
PFMECA	process failure modes, effects, and criticality analysis
PPE	personal protective equipment
PSF	performance shaping factors
RAW	risk assessment worksheet
RPN	risk priority number
SAF	Singapore Armed Forces
SPAR-H	simplified plant analysis risk human reliability assessment
THERP	technique for human error rate prediction
TSR	training safety regulations

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EXECUTIVE SUMMARY

Safety is a very important aspect of any organization because adherence to safety preserves lives, maintains confidence, and boosts productivity. Yet, injuries are not completely avoidable. Therefore, every organization and workplace should have a safety program to minimize the occurrence of injuries. The safety program should include an analysis of potential injuries and associated risk assessments of those injuries.

The Singapore Armed Forces (SAF) has an instituted safety program that utilizes a generic risk assessment method involving the 5-M (Mission, Man, Machine, Medium and Management) factor method and determines severity, likelihood, and overall level of risk through risk matrices that are similar to the ones depicted in United States Navy operation risk management OPNAV Instruction 3500.39C (Department of the Navy 2010). The Risk Assessment Worksheet (RAW) contains the results of the risk assessment.

There are several shortcomings with the current RAW technique. The categorization of the preparation, execution, and recovery phases guides the task decomposition process. However, this categorization method is too generic and vague, and results in varying degrees of completeness and thoroughness in the task decomposition. Furthermore, the current hazard identification analysis using the preliminary hazard listing and 5-M method for framing the risk assessment allows for wide interpretation as to what responses are comprehensive enough to enable the user to appreciate fully the conduct of the activity and the risks associated with each activity. This is especially so for officers who may not yet be familiar with the system. Finally, the current risk assessment technique may not provide the sufficient resolution to prioritize one risk over the other. This may result in significant risks to be obscured from the planner.

This thesis conducts a proof-of-concept study applying an alternative and well-practiced systems safety method, the Process Failure Modes, Effects and Criticality Analysis (PFMECA) and a well-known Human Reliability Analysis (HRA) method, the

Human Error Assessment and Reduction Technique (HEART), to identify hazards in SAF work processes. This thesis explores alternate methods that SAF could use to evaluate potential hazards. PFMECA is a slightly modified version of the Failure Modes, Effects and Criticality Analysis (FMECA) method.

For the purpose of analysis, this thesis selected a particular system—a work process—in the SAF. This work process is the activity of replacing one side of an armored fighting vehicle (AFV) track in the workshop. This work process was broken down into its constituent elements via a Functional Flow Block Diagram (FFBD). Thereafter, the author conducted a PFMECA analysis for the work process to determine the riskiest tasks. In addition, the author analyzed the same work process using the HEART technique and compared the results of both analyses against the RAW results.

Both PFMECA and HEART methods were more effective than RAW in hazard risk analysis. In addition, both PFMECA and HEART were equally effective at identifying the top risks. However, PFMECA would be a more useful tool for SAF because the SAF is already using the FMECA technique, a similar variant of PFMECA technique. Therefore, the organization would be familiar with the use of the tool. This would reduce the learning curve for the organization to begin using this tool and then to expand its implementation to other safety related areas. In addition, commonality across tools would keep administration efforts down and achieve ease of integration, if needed.

The layout of the PFMECA template and its intuitive, logical flow make the PFMECA technique easy to learn and apply. It is also easy to trace the logic for deriving the results of the PFMECA analysis. The reports generated using PFMECA have a logical flow, which allows drafted junior officers, hereafter referred to as junior officers, to fully understand the operational activity and the risks involved.

On the other hand, the HEART technique requires additional material like a Generic Task List and Error Producing Conditions (EPC) reference list to facilitate hazard analysis. The added requirement to understand the material may make the HEART technique difficult to implement in the SAF, given the tight training schedules

and the frequent rotation of new leaders due to drafting requirements. As such, the junior officers would have additional barriers to overcome when using this tool.

PFMECA is also a flexible tool that could be adapted and applied either to technical systems or to work processes. Many SAF operational activities include the close interaction of technical systems with human operators. While this thesis focused on the human aspect of the operational activity, it is difficult to separate the technical systems from the human activities. Since HEART analysis is not suitable to analyze technical systems, PFMECA is preferred to achieve commonality of tools and thus promote easier integration of hazard analysis for operational activities requiring close interaction of technical systems with human operators.

It is recommended that SAF embark on a one-time effort to select operations and work processes that are generally static. This could be maintenance work processes. The SAF could carry out a one-time risk assessment using PFMECA technique through teams of subject matter experts and promulgate the results as training safety regulations for all to reference. SAF leaders could continue to use the Risk Assessment Worksheet (RAW) technique as a secondary assessment method for leaders to assess the situation on the ground, right before the execution of work processes, for any new hazards that may arise from changing conditions.

LIST OF REFERENCES

Department of the Navy. 2010. *OPNAV Instruction 3500.39C—Operational Risk Management*. Washington, DC: Office of the Chief of Naval Operations.

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I. BACKGROUND

Safety is a very important aspect of any organization, because adherence to safety preserves lives. Yet, injuries are not completely avoidable and will occur on the job. Therefore, every organization and workplace should have a safety program to minimize the occurrence of injuries.

Safety is particularly important in the Singapore Armed Forces (SAF) as it shares close links to national security. In this thesis, SAF will refer only to one service—the Singapore Army (Land Forces). A small corps of salaried soldiers fills SAF's rank and file, with the vast majority being drafted soldiers. The Singapore Government drafts all Singapore male citizens reaching the age of 18 to train and serve in the SAF for a period of two years. Thereafter, they transition to the reserve force, where they will return to the SAF for refresher training every year. Because of the draft, the safety of soldiers during peacetime training and work becomes the vested interest of the entire nation. Families sacrifice two years of their sons' lives for the sake of the nation's defense and survival. This commitment to defense is heavily premised on the faith that in doing so, their son would eventually return to them safely. The servicemen and their families must be assured that safety is a top priority for the organization, even as the soldiers are put through tough and realistic training (CSNS 2014, 69).

In light of this, the Singapore Army adopted Safety as a core value in the service in 2013 (Chow 2013). According to the Singapore Ministry of Defense's narrative on their website section "Safety," "the Safety core value is hinged upon three key principles—(1) each soldier has a crucial part to play, by adopting safety as a core value and making it a way of life in his unit; (2) safety is an integral part of training, operations and mission success, and (3) safety is an individual, team and command responsibility. Being mindful of safety and adhering to safety regulations should be second nature to each individual. As members of a team, everyone must always look out for one another and take care of each other through the buddy system. Leaders play a pivotal role in setting the right safety standards, expectations and culture" (Centre for Leadership Development 2015).

The principles imply that in order for practices and processes to be safe, everyone must play a part in practicing safety, and everyone should know how to do things safely. Many of the leadership positions are held by young commissioned officers and non-commissioned officers who spent the first nine months of their army life training to assume leadership positions. The SAF then expects these junior officers immediately to transition and lead new draftees for training and work. The problem is that these junior officers are also new and need time to become familiar enough with their job to gain insights into safety issues. Furthermore, the general background of Singaporean citizens does not prepare them well for the job environment within the SAF. Therefore, the question at hand is in how best to equip the junior officers with safety knowledge for every activity that they undertake within a short amount of time? The creation of an exhaustive knowledge base of comprehensive safety analysis for every activity in the SAF could help to accelerate the junior officers' ability to internalize and appreciate these activities and their associated safety issues.

II. PROBLEM DEFINITION

A. CURRENT SAFETY PRACTICE IN SAF

Every organization and workplace should have a comprehensive safety program. The safety program should include an analysis of potential injuries and associated risk assessments of those injuries.

The SAF has an instituted safety program. Its safety management is governed by a safety management framework. This starts with the conducting officer using a set of safety regulations to implement the safety assessments. The Training Safety Regulations (TSR) includes activities like route marches, sleep cycles, munitions training, amongst many. Each TSR lists a number of regulations regarding the activity.

Using the TSR, the conducting officer implements the safety risk assessment and mitigation for the activity. The conducting officer, usually a drafted junior officer, is responsible for planning and executing the activity. In addition to his assessments on TSR, he must do another level of assessment that is based on the surrounding context and unique to the specific training he is conducting. He has to use his own experience, with the advice of more experienced officers, to conduct a safety risk assessment and mitigation before commencing use of the system. The end product of the risk assessment for the training activity is a Risk Assessment Worksheet (RAW), shown in Figure 1.

Risk Management Plan (Risk Assessment Worksheet)

Task:

Prepared by: Conducting Officer

Endorsed by: Supervising Officer

Overall Risk Level:

Sequence of Events	Identify Hazards (5-M Method)	Assess Hazards	Control Measures	Recommended Mitigation	Residual Risks
A. Preparation Phase					
B. Execution Phase					
C. Recovery Phase					

Figure 1. An Approximation of the Typical RAW Worksheet Used in the SAF.

The RAW documents all activities in the risk assessment outcomes. There are six generic steps to conduct the risk assessment for the RAW analysis process as described in Figure 2.

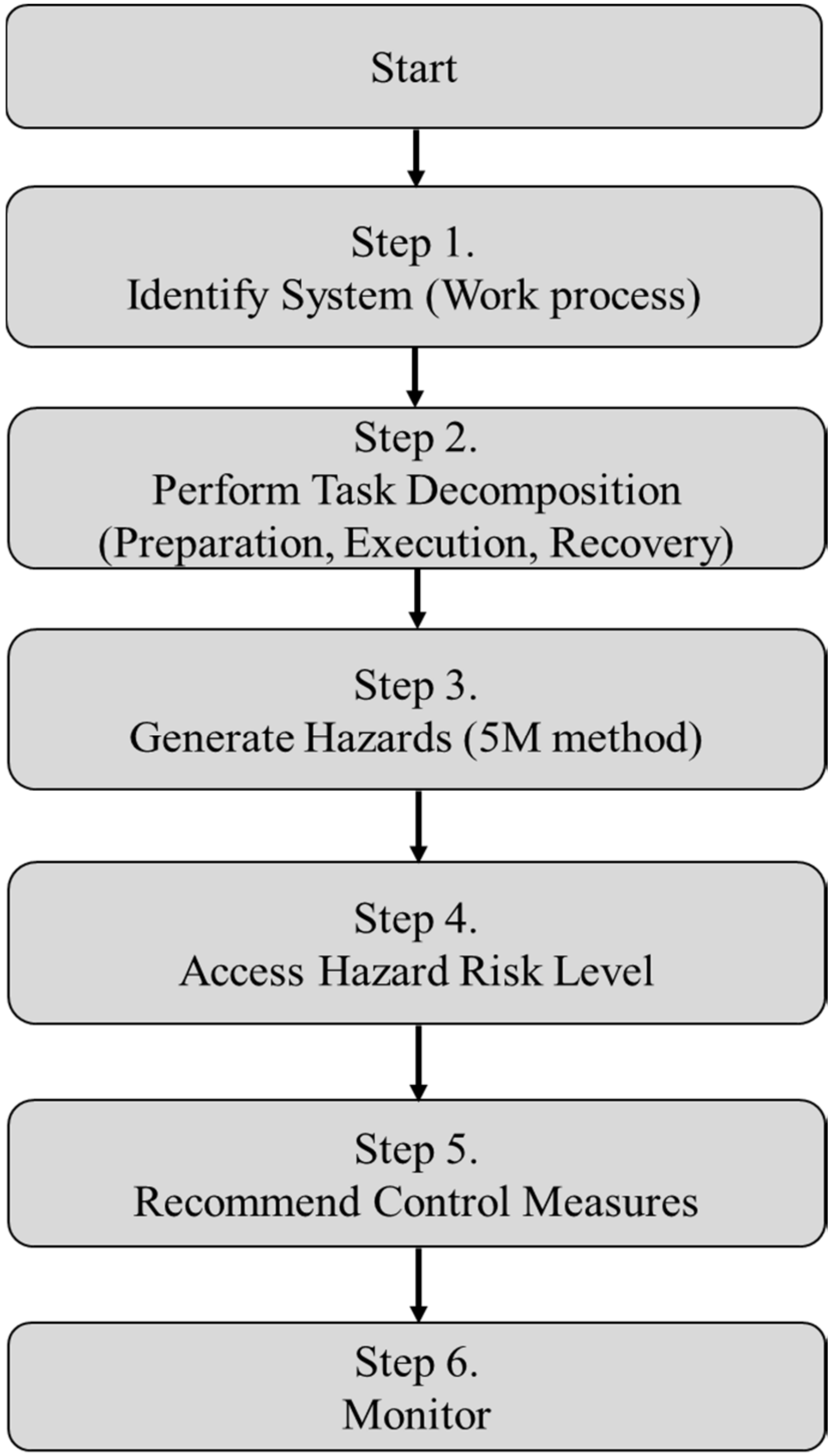

Figure 2. Steps for RAW Risk Assessment.

The conducting officer, typically a commissioned officer who is serving his two-year drafted term, would use the RAW to perform a preliminary hazard analysis. First, he would identify the system (work process) he will be planning and executing. Second, he would perform a task decomposition based on the guiding categories of preparation phase, execution phase, and recovery phase of the work process. He would list the sequence of events for the tasks under the three main categories of Preparation Phase, Execution Phase, and Recovery Phase. Hence, for the third step, he would use the 5-M factors method (Mission, Man, Machine, Medium, and Management) to identify and generate the hazards. The 5-M factors method helps to frame the safety assessment. T. P. Wright first developed this method in the late 1940s as a model for examining the nature of accidents in the aviation industry and refined the model over the years (Wells 2001). In every activity, the mission would be the activity to be conducted to achieve the intended outcome. Under the "Mission" factor, the analyst considers the complexity of the activity and whether the personnel assigned are suited for the activity. The "Man" factor refers to the personnel assigned to carry out the activity. Under this factor, the analyst considers the associated proficiency, as well as the physiological and psychological conditions of the personnel who are carrying out the tasks. The "Machine" factor refers to any piece of equipment used for the execution of the activity. The analyst considers the serviceability, ergonomics, and appropriateness of the equipment used for the activity. The "Management" factor refers to the planning, support, and supervision for the activity. "Medium" refers to the environment in which the activity is carried out and includes factors like weather and terrain. Using risk assessment matrices, the conducting officer would determine the severity, likelihood, and overall level of risk for each hazard. These matrices are similar to the ones depicted in United States Navy operation risk management OPNAV Instruction 3500.39C (Department of the Navy 2010).

B. PROBLEMS WITH CURRENT PRACTICE

There are a few shortcomings with this current risk assessment framework, namely with steps 2 to 4. Step 2 refers to perform task decomposition; step 3 refers to generate hazards; and step 4 refers to assess hazard risk level. In general, the current risk assessment method requires the conducting officer to think about the system. Using his

own experience or that of the collective knowledge, he must develop a risk assessment for the system. Experience comes in the form of other officers on the planning team, experience gained by the conducting officer during his participation in previous exercises, or knowledge gained from safety incident sharing by other colleagues.

For step 2 of task decomposition, the current categorization of preparation, execution, and recovery phases guide the process. However, those words are too generic and vague, and this lack of specific direction can result in varying degrees of detail in the task decomposition. More often than not, the task decomposition for the RAW is done at a high level instead of being broken down into component tasks for detailed analysis. Therefore, the listing of sequence of events and/or breakdown of functions could be very detailed for some but scant for others.

For step 3, the current hazard identification analysis using the preliminary hazard listing and 5-M method for framing the risk assessment allows for wide interpretation on how thorough the conducting officer must be in populating the hazard list. Therefore, the hazard list may not be comprehensive enough for the user fully to appreciate the conduct of the activity and the risks associated with each activity. This is especially so for officers who may not yet be familiar with the system.

For step 4, the current risk assessment technique may not provide the sufficient directions on how to prioritize one risk over another. According to Vincent Ho, “typical risk matrices can correctly and unambiguously compare only a small fraction of randomly selected pairs of hazards. They can assign identical ratings to quantitatively very different risks” (Ho 2010, 48). As a result, the planner may overlook some significant risks.

Therefore, a comprehensive breakdown of the work process and its corresponding risk assessment could identify more hazards and help junior officers quickly become familiar with an activity and its safety implications. This is important because despite having a safety system, organizations still experience safety lapses; many of them are a result of human error. Safety lapses could be due to systemic flaws or human error due to negligence and/or lack of enforcement. While unavoidable, these lapses show that there

may still be room for improvement in the work process, and this could be one of the ways to improve safety.

C. PROBLEM STATEMENT

The foregoing discussion points out the impetus for the current thesis research question: can the risk assessment process be strengthened with a structured and comprehensive breakdown of the system (e.g., work process, training activity, operational task) to subject it to a more thorough risk assessment technique that would identify all possible faults, system-wise or human-related? The subsequent sections explore the question in depth and propose a feasible solution that could be adopted by SAF.

III. OBJECTIVE AND METHODOLOGY

A. THESIS OBJECTIVE

This thesis explores alternate methods that SAF could use to evaluate potential hazards and conduct a proof-of-concept study to apply a well-practiced systems safety method, Process Failure Modes, Effects and Criticality Analysis (PFMECA) and a well-known Human Reliability Analysis (HRA) method, Human Error Assessment and Reduction Technique (HEART) to identify hazards in SAF work processes. PFMECA is a slightly modified version of the Failure Modes, Effects and Criticality Analysis (FMECA).

Application of alternative, potentially more comprehensive safety analysis techniques like PFMECA and HEART could prove more effective at identifying risks. This could potentially facilitate front-end risk mitigation measures and/or provide greater awareness. Even if the proposed techniques do not identify any new hazards, the exercise of deriving the hazard analysis would enhance the junior officers' understanding of the system/process in which they participate and lead to their greater awareness while executing the mission.

Currently, SAF uses FMECA in new acquisition projects to procure technical systems that are hardware and software related. SAF conducts FMECA on individual hardware and software components, considering their design and interactions from a purely mechanical standpoint. However, SAF does not apply FMECA to work processes that are typical of SAF training and operational processes. In this thesis, PFMECA is adapted to focus primarily on human-centered tasks and applied to work processes that utilize these same hardware and software components together with human operators and maintainers.

Furthermore, SAF has not used any HRA techniques, including HEART. This thesis aims to study the feasibility of adopting HEART as an alternate hazard assessment technique for human-centric work processes.

B. METHODOLOGY

Figure 3 shows a summary of the overall methodology used in this thesis. This thesis selects the work process of replacing one side of an armored fighting vehicle’s (AFV) track in the workshop for analysis purposes. First, in conducting his research, the author evaluated this process using the standard RAW analysis technique. Second, this work process was broken down into its constituent steps via Functional Flow Block Diagram (FFBD). Thereafter, the author conducted PFMECA analysis on the work process to derive the riskiest tasks. At the same time, the author also conducted a literature review to select another suitable risk assessment technique for comparison and verification of PFMECA’s results. Eventually, the HEART technique was selected and used to evaluate the same AFV work process. Finally, the author compared the results from using RAW, PFMECA, and HEART analyses.

The author of this thesis performed all analyses described in this document in the capacity of a representative user of these risk assessment methods within SAF.

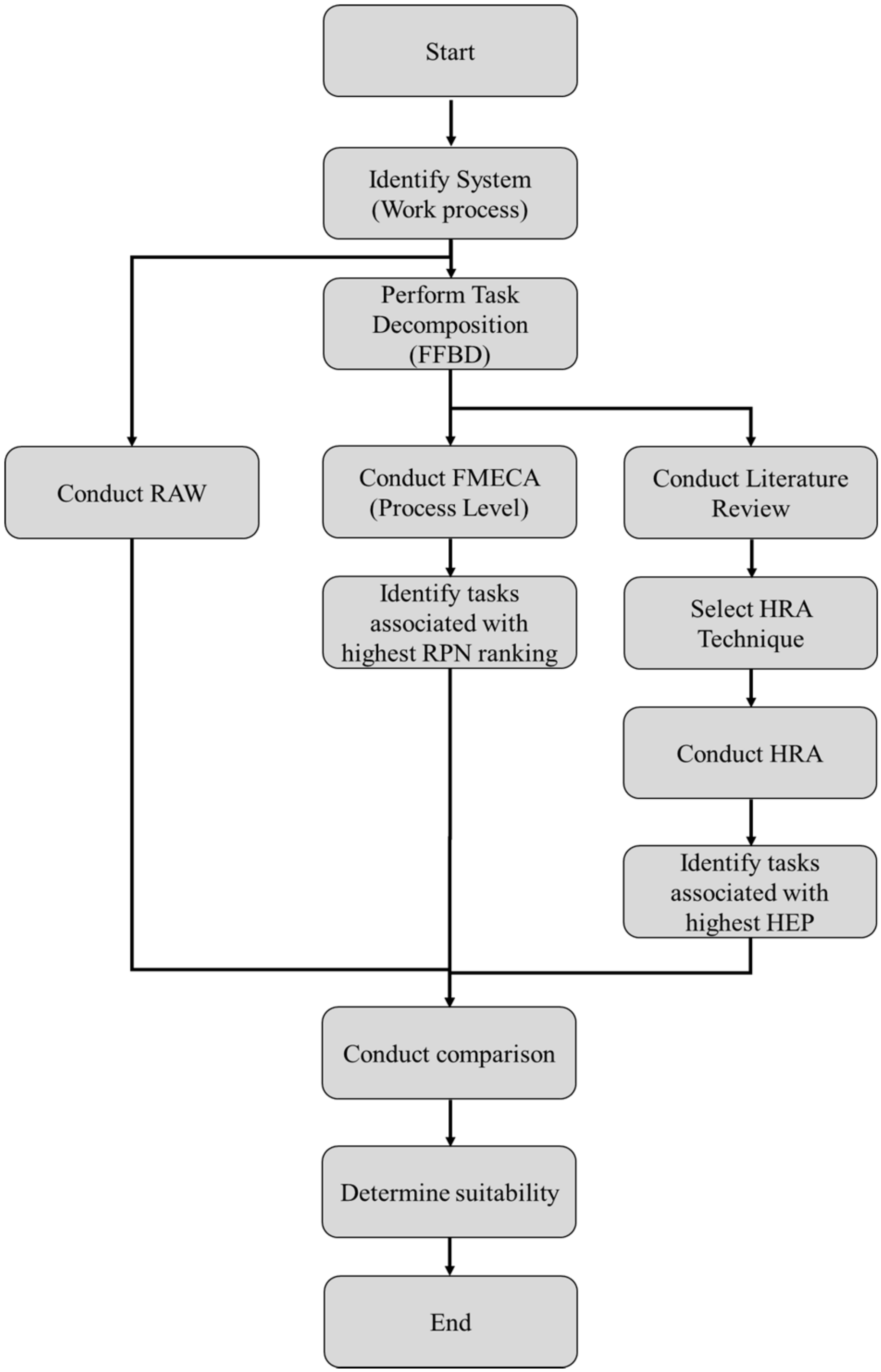

Figure 3. Methodology for Conducting Thesis Study.

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IV. SYSTEM DECOMPOSITION

A. SELECTED SYSTEM (WORK PROCESS) DESCRIPTION

The selected system is a work process within the maintenance arm of the Singapore Army. This work process describes the activity of replacing one side of an AFV track in the workshop.

This work process is generic and largely similar across all AFVs running on caterpillar tracks. Because of security restrictions related to the actual operator's manual for the specific AFV used within SAF, this thesis uses a process based upon the operator's manual for the hull section of a M3 Bradley Fighting Vehicle (BAE 1982). This vehicle was chosen because it possesses a caterpillar track sub-system design representative of the AFV in SAF. In addition, the M3 Bradley AFV's documented tasks for replacing one side of the AFV's tracks are representative of the tasks for the SAF's AFV.

The work process for replacing one side of an AFV's track in the workshop is considered an operation. The entire operation comprises setup of the workspace and the sequenced operational activities. These operational activities include more than just maintenance procedures found in the operator's manual. For example, the work process includes operational activities conducted before and after the maintenance tasks listed in the operator's manual. This allows the creation of an entire chain of operational activities involved in work process that exposes the soldiers to hazards. For example, the securing of the area of operations before the execution of the maintenance tasks and the disposal of the removed tracks after the maintenance tasks are not listed in the operator's manual, but are included as part of the work process.

B. OPERATIONAL ACTIVITY / TASK DECOMPOSITION

To formulate a logical workflow for the operation, it is important to select and re-arrange the relevant individual operation and/or maintenance procedure. The work process represents a holistic and logical view of the entire operation that an SAF maintenance team has to undertake. In this way, the subsequent risk analysis would be

able to cover more areas of the operation and potentially identify more problems rather than conducting the analysis using the individual maintenance procedures within the operator’s manual.

From the operator’s manual, the author distilled the relevant operational activities and merged them into the maintenance work process of replacing one side of an AFV’s track in the workshop setting. This was supplemented with the author’s experience to develop this work process. The author is a maintenance officer with the SAF with four years of experience with maintenance operations, having served the last two years as a maintenance depot commander.

The author created a Functional Flow Block Diagram to clearly depict the translation of tasks described in the operator’s manual for the purpose of this analysis. Table 1 shows the high level summary of the operational activities and task decomposition of the work process sequentially. Level 1 shows the highest level of each task within the work process. They are assigned the numbers 1.0 to 13.0 to represent the corresponding steps in the operational activity, with number 1.0 representing the first step and number 13.0 representing the last step of the activity. Levels 2 and 3 show the sub-tasks associated with the corresponding higher level tasks. With specific reference to this work process, Level 3 corresponds to the lowest level of task decomposition and is sufficiently simple for effective hazard analysis using PFMECA and HEART. “Nil” entries mean that the associated higher level task has been decomposed to its simplest form; there are no further sub-tasks associated with the higher level task. It should be noted that this level of task decomposition is not required within the RAW technique.

These numbers were consistent across the task decomposition table and the FFBD. Appendix A shows a detailed breakdown of the operational activities and task decomposition. The author generated an FFBD to illustrate the relationships between the high level activities and their sub-tasks better. The FFBD decomposed the operational activity into three levels. Figure 4 shows the overall FFBD, with the first two levels of the decomposition. Figures 5 to 8 show the enlarged views of the FFBD, broken down into different phases of the operational activity. Appendix A shows the detailed breakdowns to the third level of decomposition.

To display the work process in a logical and sequential form, some of the operational activities, with their corresponding tasks, may be repeated. Therefore, Table 1 and Figures 4 to 8 are color coded to display the repeated operational activities. Table 2 shows a short summary of the repeated tasks. It is likely that there would be slight differences in the objectives of each repeated task, and Table 2 shows the detailed description as well.

Table 1. High-Level Summary of the Operational Activities and Tasks for the Selected Work Process

Level1 ID (Match with FFBD)	**Operational Activities**	**Level2**	**Operational Tasks**
1.0	Secure Area	1.1	Identify Area of Operations
		1.2	Cordon off area
2.0	Position Vehicle	2.1	Enter Vehicle
		2.2	Start Engine
		2.3	Drive vehicle into position
		2.4	Stop Vehicle
		2.5	Stop Engine
		2.6	Exit Vehicle
3.0	Break Track	3.1	Unstow track fixtures and drift pin
		3.2	Loosen track tension
		3.3	Remove track pin (used track shoes)
4.0	Position Vehicle	4.1	Enter Vehicle
		4.2	Start Engine
		4.3	Drive vehicle into position
		4.4	Stop Vehicle
		4.5	Stop Engine
		4.6	Exit Vehicle
5.0	Dispose old track	5.1	Remove track pin (from old track shoes)
		5.2	Shift track links
6.0	Form Track	6.1	Shift track links
		6.2	Remove track pin (from new track shoes)
		6.3	Join track shoes
		6.4	Torque nut
7.0	Position Vehicle	7.1	Enter Vehicle
		7.2	Start Engine

Level1 ID (Match with FFBD)	Operational Activities	Level2	Operational Tasks
		7.3	Drive vehicle into position
		7.4	Stop Vehicle
		7.5	Stop Engine
		7.6	Exit Vehicle
8.0	Position Track (Initial)	8.1	Check track guide position
		8.2	Guide track over Sprocket
9.0	Position Vehicle	9.1	Enter Vehicle
		9.2	Start Engine
		9.3	Drive vehicle into position
		9.4	Stop Vehicle
		9.5	Stop Engine
		9.6	Exit Vehicle
10.0	Position Track	10.1	Check track guide position
		10.2	Guide track over Sprocket
11.0	Join Track (while on vehicle)	11.1	Assemble track fixtures
		11.2	Install track fixtures
		11.3	Join track shoes (while on vehicle)
		11.4	Torque nut
		11.5	Remove track fixtures
12.0	Adjust Track tension	12.1	Check track tension
		12.2	Tighten track tension
		12.3	Loosen track tension
13.0	Position Vehicle	13.1	Enter Vehicle
		13.2	Start Engine
		13.3	Drive vehicle into position
		13.4	Stop Vehicle
		13.5	Stop Engine
		13.6	Exit Vehicle

The same tasks may generate different risks and/or risk levels when performed under different contexts. For example, the same task, when performed in the day as opposed to at nighttime, could affect the operator’s ability to see, and the disruption of the circadian cycles could present additional risks when the task is performed at night. However, for the repeated tasks in this activity, the author assessed that these tasks have no relevant differences in context that would affect the risk analysis outcomes. The

author analyzed each repeated task for any differences that could contribute to changes in the risk assessment outcomes. The author considered variation in several factors like the surrounding environment, the time periods of conducting an activity, and the group of personnel conducting the tasks. In addition, he also considered whether there were prolonged periods where personnel performed the tasks continuously.

Changes in the surrounding environment could cause new hazards. For example, carrying out the task in the field environment would have additional hazards such as uneven ground, higher risk of heat injuries when wearing body armor, and higher risks of injuries as a result of range-of-motion limitations caused by cumbersome body armor. In this operational activity, the entire operational activity was carried out in the same workshop environment.

Changes in time period of conducting an activity would have an impact on the hazards. For example, the act of carrying out a task in the day could be very different from carrying out a task at night. It would be riskier to carry out the task at night because of low visibility and the disruption of a person's circadian cycle leading to lack of sleep, which would increase probability of error. The operational activity analyzed in this thesis was slated to take place during business hours, under daylight conditions.

Changes in the weather could cause risk assessment outcomes to be different. However, it would be hard to predict which task would be subject to inclement weather. Furthermore, during inclement weather, work activities would be temporarily stopped. Hence, the operational activity was assumed to be carried out under the same weather conditions, and thus this factor was not considered to have any impact on the risk assessment outcome of the operational activity.

Changes in personnel carrying out the task could impact the risk assessment outcomes. This largely refers to the skill of these personnel. Personnel with fewer, or irrelevant skills, would be at higher risk of sustaining injury. In this operational activity, the same set of personnel executed the tasks throughout. Typically the set of personnel would come from the same group of draftees, have the same demographic characteristics,

and have undergone the same training phases before being assigned to units. Therefore, the risk levels specific to their skills remain the same.

Prolonged periods of performing tasks could impact the risk assessment outcome. However, personnel with the same relevant skills would be assigned to the operational activity and would take turns carrying out the task. Therefore, risks associated with prolonged or repeated task execution, such as dulling of senses and fatigue, would have minimal impact on an operational activity. For example, in the repeated task of positioning the vehicle, the driver and ground guides would have sufficient rest in between tasks, the area of operations for executing the operational activity would be the same, and the mechanical actions would be exactly the same. Therefore, subsequent analysis omitted the repeated tasks.

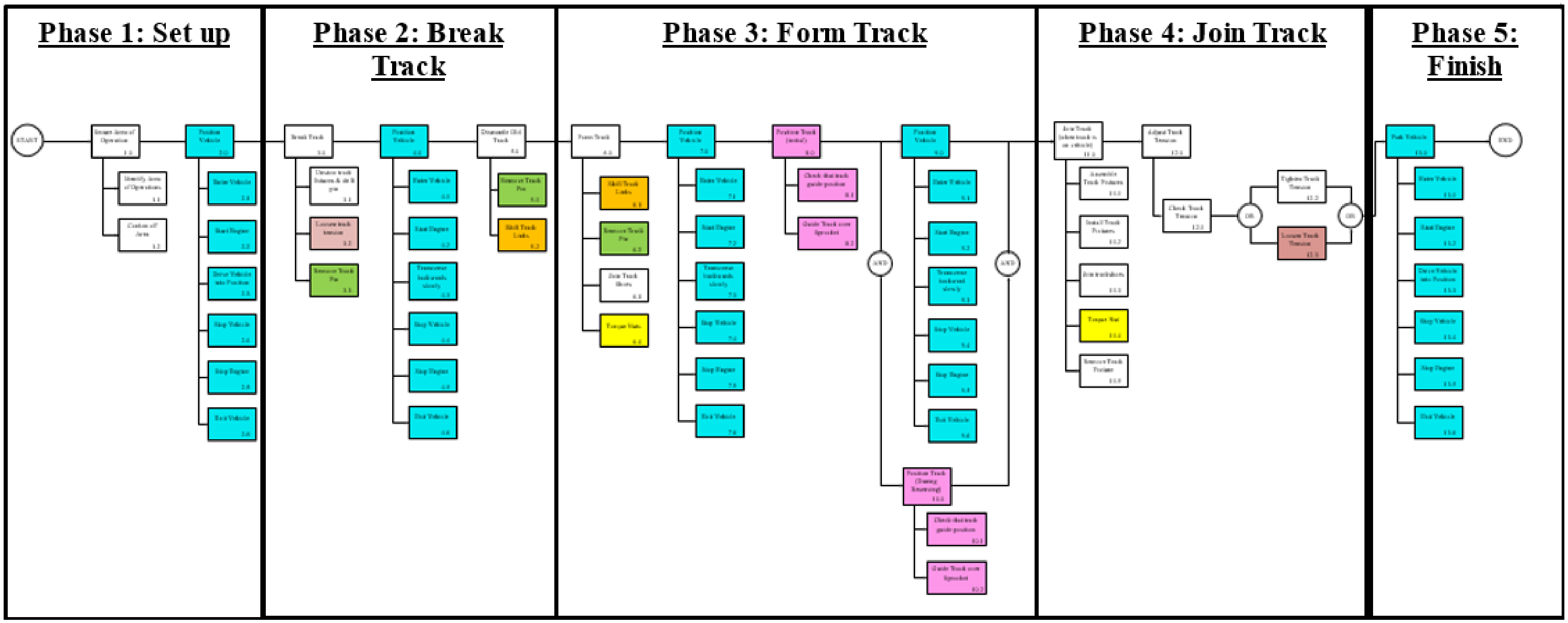

Figure 4. An Overall FFBD View of the Work Process.

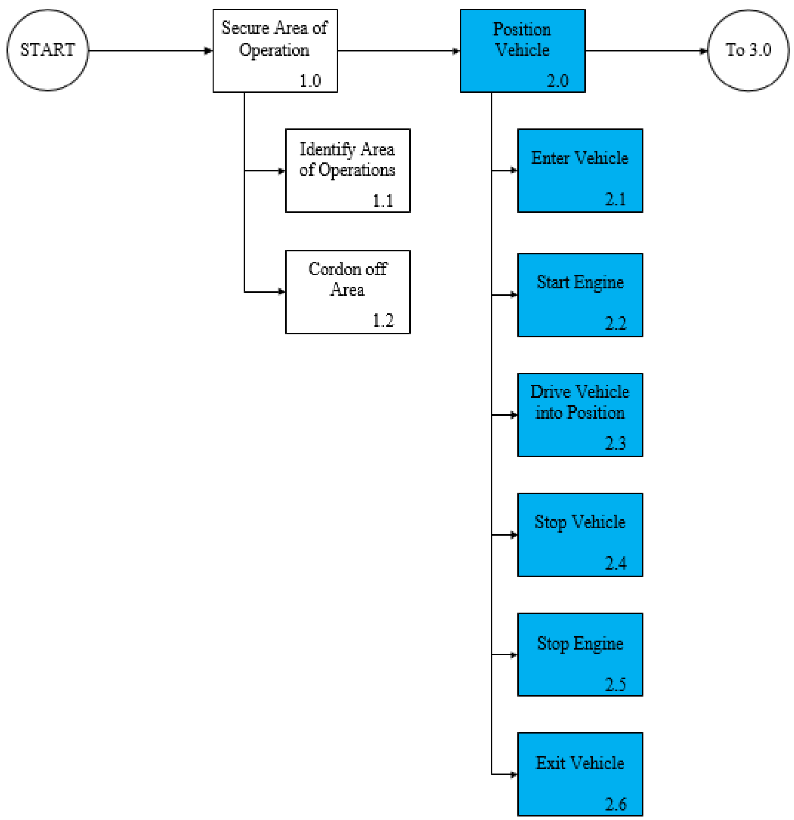

Figure 5. An Enlarged View of the Work Process FFBD (Phase 1).

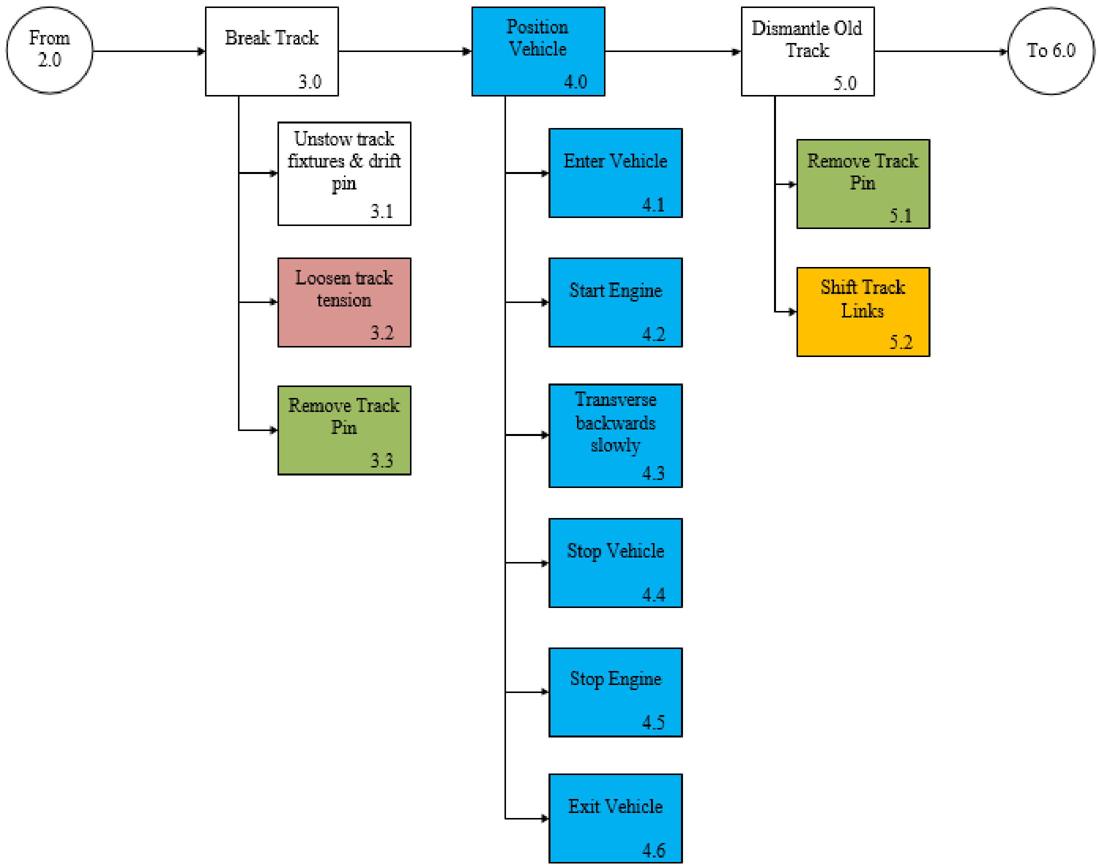

Figure 6. An Enlarged View of the Work Process FFBD (Phase 2).

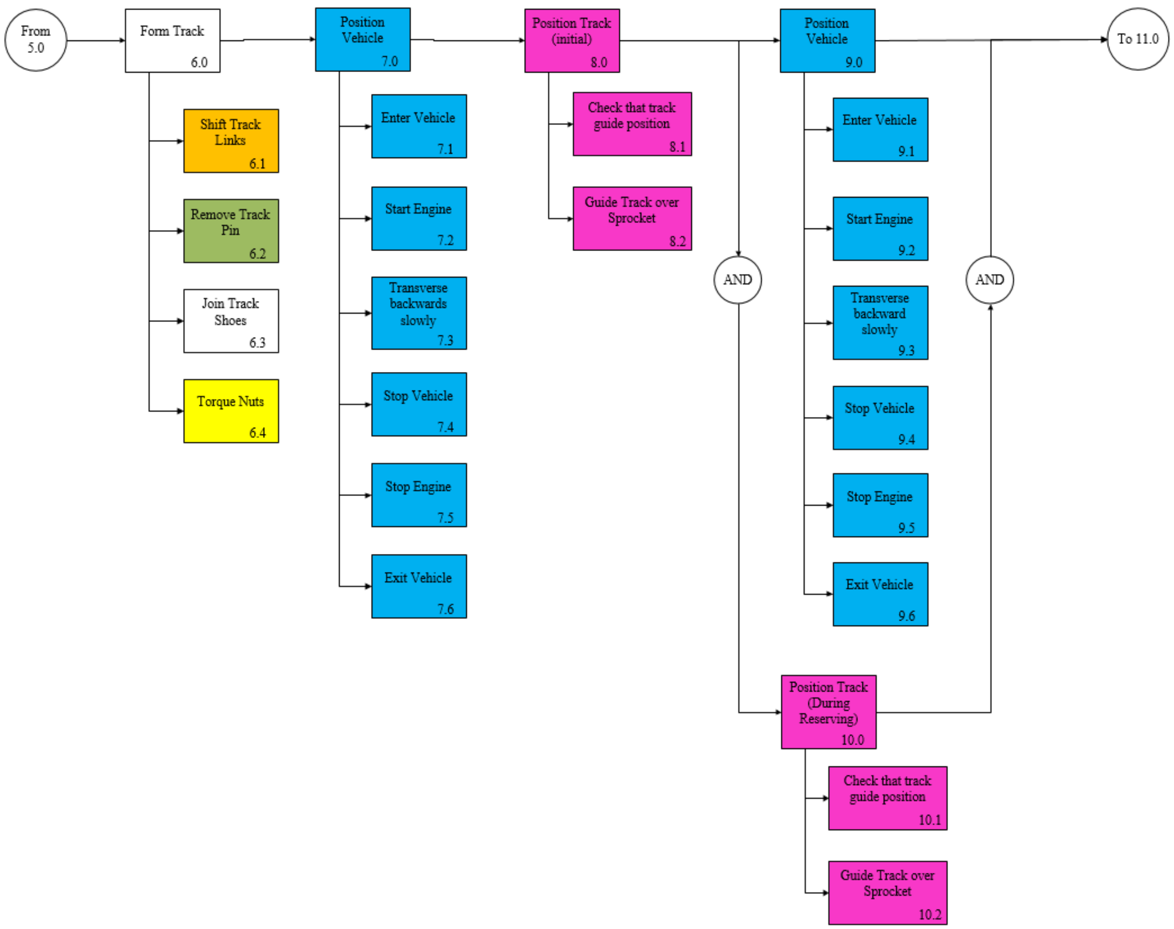

Figure 7. An Enlarged View of the Work Process FFBD (Phase 3).

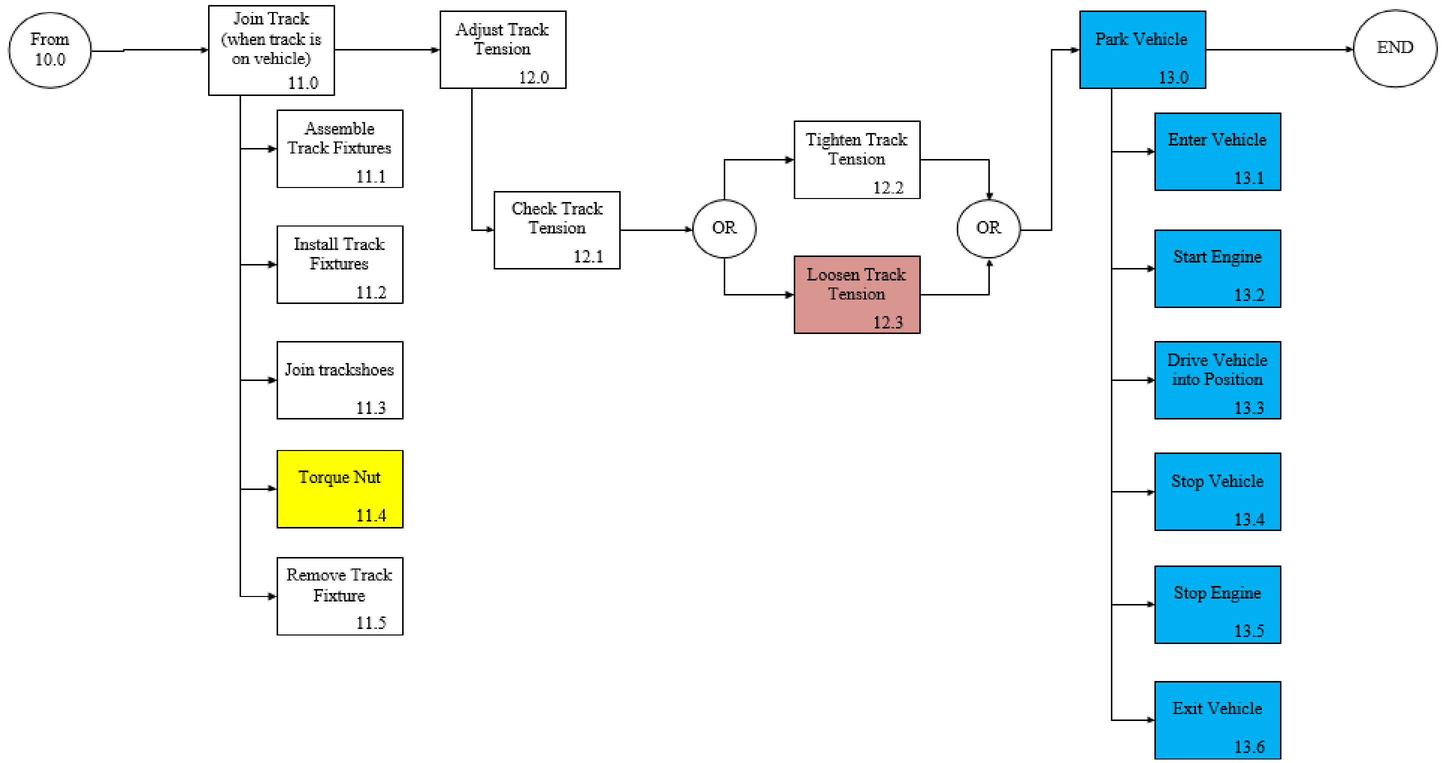

Figure 8. An Enlarged View of the Work Process FFBD (Phases 4 and 5).

Table 2. A Brief Summary of the Color Coded Operational Activities and/or Tasks.

Color Code	Operational Activity	Level	Description
	Position Vehicle	2.0	To drive the vehicle from parking lot into area of operations.
		4.0	To move the vehicle backwards, so that the old track will fall out and end up in front of the vehicle.
		7.0	To move the vehicle forward, so that the vehicle can mount onto the NEW track links, and move along the track until the first road wheel reaches the 9th track shoe (counting from the first track shoe that was initially furthest away from vehicle).
		9.0	To move the vehicle backward, so that the backward rotation of the sprocket will force the track to move up and back over the top of the sprocket and along the top of the road wheels.
		13.0	To drive the vehicle back to the parking lot.
	Loosen Track Tension	3.2	To loosen track tension, to facilitate the breaking of OLD tracks.
		12.3	To loosen track tension if the track is found to be too tight after joining the NEW tracks.
	Remove Track Pins	3.3	To remove Track Pins from NEW track shoes, to link the two separate pieces of Track Links together.
		5.1	To remove Track Pins from OLD track shoes, to break apart the OLD Track into separate Track Links.
	Shift Track Links	5.2	To move the OLD Track Links to disposal cage for disposal.
		6.1	To move the NEW Track Links to Area of Operations.
	Torque Nut	6.4	To torque the Track Pin nuts after joining the track shoes together, to prevent the nuts from loosening during operations.
		11.4	The purpose is exactly the same as 6.4.
	Position Track	8.0	To lift the first 9 track shoes and guide them over the sprocket wheel. The track shoe has to be fitted onto the teeth of the sprocket wheel.
		10.0	To maintain the position of the first 9 track shoes and ensure that the track shoes are still fitted onto the teeth of the sprocket wheels. This is a concurrent activity, as the vehicle is moving backward.

C. EXAMPLE RAW

For meaningful comparisons to be made, an example RAW was done, and Table 6 shows the analysis results. The example RAW would be the basis of comparison with the FMECA and HEART processes.

It is important to note that RAW does not require an FFBD. Instead, with RAW, one only needs to divide the operational steps of replacing one side of an AFV's track into only three possible categories: Preparation, Execution, and Recovery.

For each hazard, the severity, probability, and corresponding risk levels were determined. Severity was determined by the potential consequence that would have occurred as a result of the hazard. It was determined by assessing the injury severity, loss of time, money, personnel and/or ability to achieve the mission. For probability, this was to determine the likelihood that a potential consequence may happen due to the hazard. Finally, the corresponding risk levels were determined by matching them to the risk assessment matrix. Tables 3 to 5 show an example of the severity table, probability table, and risk assessment table, respectively.

Table 3. Severity Table

Severity	Description
Catastrophic	Resulting in complete mission failure Resulting in death or is life threatening
Critical	Resulting in significantly degraded mission capability Resulting in major injury to personnel
Marginal	Resulting in degraded mission capability Resulting in minor injury to personnel
Negligible	Resulting in insignificant or zero impact to mission Resulting in minor or no injury to personnel

Table 4. Probability Table

Probability	Description
Frequent	Always occurs or happens most of the time
Likely	Happens often
Occasional	Occurs sometimes or irregularly
Seldom	Remotely possible
Unlikely	Not likely to happen but not impossible

Table 5. Risk Assessment Matrix

Severity	**Probability**				
	Frequent	**Likely**	**Occasional**	**Seldom**	**Unlikely**
Catastrophic	Extremely High	Extremely High	High	High	Medium
Critical	Extremely High	High	High	Medium	Low
Marginal	High	Medium	Medium	Low	Low
Negligible	Medium	Low	Low	Low	Low

Table 6. An Example of a RAW

Sequence of Events	Hazard ID	Identify Hazards (5-M Method)	Assess Hazards		
			Severity	Probability	Risk Level
<u>A. Preparation Phase</u>	-				
Securing the Area	RAW.1	<u>Management</u>. Insufficient space may be catered	Negligible	Occasional	Low
	RAW.2	<u>Man</u>. Inadequate rest the night prior	Critical	Occasional	High
	RAW.3	<u>Man</u>. Inadequate hydration prior to activity	Critical	Occasional	High
	RAW.4	<u>Man</u>. Inadequate skillset for the task	Critical	Occasional	High
	RAW.5	<u>Medium</u>. Inclement weather	Critical	Occasional	High

Sequence of Events	Hazard ID	Identify Hazards (5-M Method)	Assess Hazards		
			Severity	Probability	Risk Level
Position Vehicle	RAW.6	Machine. Vehicle may malfunction	Critical	Seldom	Medium
	RAW.7	Man. Inadequate rest the night prior.	Critical	Occasional	High
	RAW.8	Man. Poor communication between ground guides and driver.	Catastrophic	Occasional	High
B. Execution Phase	-				
Break Track	RAW.9	Man. Poor communication between personnel working together.	Critical	Likely	High
	RAW.10	Man. Inadequate skillset for the task	Critical	Occasional	High
	RAW.11	Man. Under stress to complete the task quickly.	Critical	Occasional	High
	RAW.12	Man. Reckless attitude	Critical	Occasional	High
	RAW.13	Management. Insufficient rest time between activities	Critical	Occasional	High
	RAW.14	Machine. Vehicle may malfunction	Critical	Seldom	Medium
Form Track	RAW.15	Man. Poor communication between personnel working together	Critical	Likely	High
	RAW.16	Man. Inadequate skillset for the task	Critical	Occasional	High
	RAW.17	Man. Under stress to complete the task quickly	Critical	Occasional	High
	RAW.18	Man. Reckless attitude	Critical	Occasional	High
	RAW.19	Man. Improper lifting technique	Critical	Occasional	High
	RAW.20	Man. Inadequate strength	Critical	Occasional	High

Sequence of Events	Hazard ID	Identify Hazards (5-M Method)	Assess Hazards		
			Severity	Probability	Risk Level
	RAW.21	Management. Insufficient rest time in between activities	Critical	Occasional	High
C. Recovery Phase	-				
Dispose of Track	RAW.22	Man. Improper lifting technique	Critical	Occasional	High
	RAW.23	Man. Inadequate strength	Critical	Occasional	High
	RAW.24	Man. Poor communication between personnel working together.	Critical	Likely	High
	RAW.25	Medium. Slippery floors may cause slip hazard	Critical	Seldom	Medium

V. CHOOSING ALTERNATE RISK ASSESSMENT METHOD

A. FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS (FMECA)

There are many risk assessment techniques available, each suited for different purposes and covering different levels of detail. For this thesis, the PFMECA technique is selected.

In its original form, the Failure Modes, Effects Analysis (FMEA) technique is a bottom-up, step-by-step approach for identifying all possible failures in a system. Both the FMECA and PFMECA techniques are variants of the FMEA technique. The FMECA technique, which SAF currently uses, is basically the same as the FMEA technique, except that it adds criticality analysis to the failure modes and also includes the analysis of possible failure mode detection methods (Ericson 2005). The FMECA technique adds value to the FMEA process by evaluating the criticality of the failure modes.

Even within the FMECA technique, there are different approaches and variations. The manufacturing industry developed the PFMECA specifically for work processes (Raheja and Gullo 2012). PFMECA differs only slightly from FMECA in that it includes two additional columns to aid in the analysis process. They are “Process Name and Description” and “Process Step,” for easier implementation when assessing work processes. Table 7 shows a brief summary of the techniques described previously.

Table 7. Brief Overview of FMEA and the Variants Described in this Thesis.

Technique Name	Description
FMEA	A bottom-up, step-by-step approach for identifying all possible failures in a system
FMECA	FMEA with added criticality analysis
PFMECA	FMECA with added columns, “Process Name and Description” and “Process Step” for easier implementation when assessing work processes

The PFMECA technique is a procedure-based qualitative risk assessment technique that the practitioner can use to identify a system (product or process) weakness

(Blanchard and Fabrycky 2011, 385). According to Blanchard and Fabrycky, it includes the required step-by-step procedure that allows the practitioner to scrutinize and evaluate all possible pathways in which a system can fail, the potential failure effects, and the consequences of these effects. In addition, they also mentioned that although it is best to use PFMECA to impact design upfront in the system life cycle, PFMECA also can evaluate and improve existing systems on a continuing basis. The PFMECA technique is a disciplined bottom-up evaluation risk assessment technique. It can evaluate potential failure modes of the subsystems, assemblies, components or functions. This ties in well with the FFBD breakdown of the system (Ericson 2005). As such, using the PFMECA will help improve task decomposition process due to the need to analyze the work process from the bottom up. Furthermore, since the PFMECA analysis approach facilitates the thorough generation and identification of possible hazards, this could potentially address one of RAW’s shortcomings.

For this thesis, the author selected the PFMECA technique as an alternate risk assessment method because its close variant, the FMECA, was already in use in SAF. In systems development and acquisition processes, SAF practitioners have been using the FMECA technique regularly to improve system reliability in technical systems and systems acquisition. If the PFMECA technique proved suitable for operational work processes to improve safety in the SAF, there would be a common framework in the SAF and, therefore, make its adoption easier. Furthermore, FMECA is probably the most widely applied risk assessment technique in industry (Moradi 2010). Using a tried and tested technique will make it easier to adopt and accept the technique for use in SAF.

As PFMECA is a qualitative or semi-quantitative process, it is uncomplicated and can be easily learned and understood. This makes it ideal for SAF, most of whose officers have only about one year of service in their active units after graduating from their vocational training schools. In addition, PFMECA has been widely used in many industries. The PFMECA technique also has been applied to maintenance processes in the military context (Yanliang et al. 2011).

B. PROCESS-FMECA (PFMECA)

There is a nine-step procedure for conducting PFMECA. The procedure for conducting PFMECA in this thesis refers to Clifton A. Ericson II's *Hazard Analysis Techniques for System Safety* (Ericson 2005), and was modified for this analysis to focus on human-centered tasks. This assumes that the technical assessment of the system's hardware and software subsystems and components has been done during the system acquisition phase; and, the design of the system has been refined to remove failures due to component failures. This keeps the PFMECA process manageable for this thesis. Table 8 lists the steps for PFMECA. For the purpose of this thesis, steps 3, 7, 8, and 9 from Table 8 were omitted. This was because the author developed the PFMECA for a team, and since there was no actual execution of the operational activities, there would be no requirement to monitor, track, and document the PFMECA. The Risk Priority Number (RPN) was calculated as the product of the Severity, Occurrence, and Detectability values. There were no definitive RPN threshold values to decide the cut-off values, as this depends on many factors, including organization risk appetites, legal or safety requirements, and quality control. The author performed a descriptive statistical analysis on the 200 PFMECA RPN values, created a cumulative frequency curve, and selected the top five percent of the values to be analyzed. As such, the cut-off RPN was 400. Therefore, for the thesis analysis, the threshold values for PFMECA RPN were set at 400. Therefore, failures with RPN greater than 400 would be considered unacceptable, and recommended corrective actions would be prescribed. Table 9 shows the format for FMECA template to be used while Tables 10 to 12 show the severity scale, occurrence scale, and detection scale that were used, respectively.

Table 8. Steps for Conducting PFMECA. Adapted from Ericsson (2005).

Step	Task	Description
1	Define System	Define, scope, and bound the system. Define the mission, mission phases, and mission environments. Understand the system design and operation
2	Plan PFMECA	Establish PFMECA goals, definitions, worksheets, schedule, and process. Start with functional PFMECA then move to PFMECA of hardware that is safety critical (identified from functional PFMECA). Divide the system under analysis into the smallest segments desired for the analysis. Identify items to be analyzed and establish indenture levels for items / functions to be analyzed
3	Select Team	Select all team members to participate in PFMECA and establish responsibilities. Utilize team member expertise from several different disciplines (e.g., design, test, manufacturing)
4	Acquire Data	Acquire all of the necessary design and process data needed (e.g., functional diagrams, schematics, and drawings) for the system, subsystems and functions for FMECA. Refine the item indenture levels for analysis. Identify realistic failure modes of interest for the analysis. Identify realistic failure modes of interest for the analysis and obtain component failure rates
5	Conduct PFMECA	1. Identify and list the items to be evaluated 2. Obtain concurrence on the list and level of detail 3. Transfer the list to the PFMECA worksheet 4. Analyze each item on the list by completing the PFMECA worksheet questions 5. Have the PFMECA worksheets validated by a system designer for correctness
6	Recommend Corrective Action	Recommend corrective action for failure modes with unacceptable risk Assign responsibility and schedule for implementing corrective action
7	Monitor corrective action	Review test results to ensure that safety recommendations and system safety requirements are effective in mitigating hazards as anticipated
8	Track hazards	Transfer identified hazards into the hazard tracking system
9	Document PFMECA	Document the entire PFMECA process on the worksheets. Update for new information and closure of assigned corrective actions

Table 9. FMECA Template

PFMECA										
System			**Subsystem**				**Mode/ Phase**			
Item	**Potential Failure Mode**	**Effects**	**Severity**	**Potential Causes of Failure**	**Occurrence**	**Detection Method/Design Controls**	**Detection**	**RPN**	**Actions Recommended to Reduce RPN**	**Responsibility and Target Completion Date**

Table 10. Severity Scale for PFMECA. Adapted from Reichert (2004).

Severity Scale		
Scale	**Description**	**Definition**
1	No danger	Failure causes no injury and has no impact on the system
2	Slight danger	Failure causes no injury. However, the potential for minor injury exists. There is little or no effect on the system
3 - 4	Low to Moderate danger	Failure causes very minor or no injury, and/or results in minor system problems that can be overcome with minor modifications to system
5 - 6	Moderate danger	Failure causes minor injury with some personnel dissatisfaction, and/or major system problems
7	Dangerous	Failure causes minor to moderate injury, and/or major system problems requiring major repairs or significant rework
8 - 9	Very dangerous	Failure could cause major or permanent injury to personnel (work crew or external personnel), and/or could cause serious system disruption with interruption in service, with prior warning
10	Extremely dangerous	Failure could cause death of a personnel (work crew or external personnel), and/or could cause total system breakdown without any prior warning

Table 11. Occurrence Scale for PFMECA. Adapted from Reichert (2004).

Occurrence Scale		
Scale	**Description**	**Definition**
1	Remote probability of occurrence	Failure almost never occurs; and, no one remembers the last failure
2	Low probability of occurrence	Failure occurs rarely; or, failure occurs once per year
3 - 4	Moderate probability of occurrence	Failure occurs occasionally; or, failure once every three months
5 - 6	Moderately high probability of occurrence	Failure occurs about once a month
7 - 8	Very high probability of occurrence	Failure occurs frequently; or, failure occurs about once a week
9	Failure is almost inevitable	Failure occurs predictability; or, failure occurs every 3 or 4 days
10	Certain probability of occurrence	Failure occurs at least once a day; or, failure occurs almost every time

Table 12. Detection Scale for PFMECA. Adapted from Reichert (2004).

Detection Scale		
Scale	**Description**	**Definition**
1	Almost certain	There are automatic “shut-offs” or constraints that prevent failure.
2	Very high	There is 100% inspection of the process and it is automated.
3 - 4	High	There is 100% inspection or review of the process but it is not automated.
5	Moderate chance of detection	There is process for double-checks or inspection but it is not automated and/or is applied only to a sample and/or relies on vigilance.
6 - 7	Remote	The error can be detected with manual inspection but no process is in place so that detection is left to chance.
8 - 9	Very remote/unreliable	The failure can be detected only with thorough inspection and this is not feasible or cannot be readily done.
10	No chance of detection	There is no known mechanism for detecting the failure.

C. PERFORMING PFMECA ON SELECTED SYSTEM

The author performed the PFMECA analysis on the work process of replacing one side of an AFV in the workshop environment. To keep the PFMECA manageable for the purpose of this thesis, the hardware and component level failures were ignored except for the most critical ones that directly interface with human actions. Table 13 shows an example from the completed analysis. Appendix B shows the detailed analysis, including the fully worked PFMECA table.

For each lowest level task, in this case 2.1.1—climb onto top of vehicle, the expert team would brainstorm on the potential failure modes. In the thesis, the author served as a representative user for this analysis, as well as a subject matter expert on the AFV repair activity. For each of the failure modes, the failure effects were described. The severity of each failure effect was assigned a number from the Severity Scale in Table 10. Thereafter for each failure mode, all possible potential causes of the particular failure mode would be noted and assigned a probability of occurrence. Since these failure modes were related to human actions and errors, the failure modes were referenced from the *Handbook of Human Factors and Ergonomics* (Sharit 2012). The error modes selected were timing, force, distance and/or magnitude, speed, and direction. Timing determines when actions are performed too early or too late, or omitted. Most of the actions involved coordination and timing that could affect the safety outcomes. Force refers to actions performed with insufficient or too much force. This is applicable because of the mechanical nature of the tasks involved. The mechanical actions involving generating movements and arm swings make distance and/or magnitude and direction applicable.

For the completed example in Table 13, work environment and/or work schedule was one of the contextual factors that could influence human performance. Factors such as time constraints would have a negative impact on human performance and might lead to human error. For each of these failure causes, the author determined and assigned a value. If there were control measures to enhance detectability, the detectability would generally be higher and, hence, assigned a lower number.

The author ranked these resulting failure causes and associated tasks according to the RPN values, from the highest to the lowest. Table 14 shows the rank of failure causes and associated tasks that had RPN values above 400. In this aspect, the risk associated with each task took on the RPN value of the failure cause that generated the highest RPN.

For all tasks, the people at risk of committing the mistakes and/or sustaining injuries were the technicians who carried out those tasks. However, in the task of positioning the vehicle, the driver and ground guides were at risk of committing the mistakes while the technicians were at risk of sustaining injuries.

Table 13. Example of PFMECA Analysis

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls	C) Detection (1-10) 10=least detectable	RPN AxBxC
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	PFMECA.16	Failure to gain proper footing on latches	Fall from height (up to 2 meters), leading to fall injuries	9	Slippery Footholds due to presence of water, oil and/or grease	2	Manual Inspection by crew (not an included process)	6	108
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	PFMECA.17	Failure to gain proper footing on latches	Fall from height (up to 2 meters), leading to fall injuries	9	Time constraints leading to rushing of actions	6	Supervision by Section Commander (relies on vigilance)	5	270
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	PFMECA.18	Failure to maintain balance on top of the vehicle	Fall from height (up to 2.6meters), leading to fall injuries	9	Slippery surfaces due to presence of water, oil and/or grease	2	Nil	6	108
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	PFMECA.19	Entanglement of wearables (i.e. necklace, ring, loose clothing, bootlaces)	Impeded movement may cause loss of balance	8	Loose apparel	2	Nil	6	96

Table 14. Tasks with RPN Above 400

Level 1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID	RPN AxBxC
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.168	480
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.99	441
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.64	432
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.102	432
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.105	432
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.106	432
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit Shoe	PFMECA.113	432
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit Shoe	PFMECA.117	432
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit Shoe	PFMECA.120	432
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit Shoe	PFMECA.121	432
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.179	432
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.167	400

D. RESULTS

Key results of the PFMECA analysis show that the most critical failure modes arose from the operational activities of breaking track, forming track, positioning track, and positioning vehicle, as shown in Table 14. Aside from the operational activity of positioning the vehicle, all other operational activities involved manual labor and the use of associated labor tools like crowbars, sledgehammers, and wrenches. These activities were associated with high severity if failure happens. When too much force is used, the blunt force trauma to human bodies with uncontrolled force and heavy objects could result in severe injuries.

The occurrence of failures associated with these activities was also high. This is normal because the soldiers generally have not been exposed to heavy and manual labor prior to being drafted. Furthermore, training and practice during training schools is limited because of the trainees-to-equipment ratio. Therefore, it would be difficult to familiarize the soldiers with handling these tools and their use.

Using the PFMECA technique, the author generated a sizeable number of faults, 200 failure causes as opposed to the 25 generated by RAW. Compared to the RAW, the PFMECA was better than the RAW in steps 2 to 4 of the risk assessment process. For step 2, task decomposition, the PFMECA technique necessitated a thorough breakdown of the activity into the component tasks, while RAW did not, and only specified three broad areas to be analyzed: preparation, execution, and recovery phases. The RAW produced only five broad operational activities. The vague guidelines on the categorization for task decomposition did not prompt a rigorous thought process for breaking down the operational activity into simple tasks. Furthermore, the subsequent 5-M factor method did not necessitate a detailed breakdown of tasks in order for hazard identification to take place. As such, the RAW technique produced fewer operational activities in this case. On the other hand, PFMECA, through the necessary use of FFBD task decomposition, forced the author to generate 13 operational activities, 53 Level 2 tasks and 175 Level 3 tasks.

With its thorough task decomposition, the PFMECA analysis produced many more failure modes and effects than RAW did for step 3. The PFMECA technique requires a review of every step of the operational activity for potential failure modes and effects. For example, RAW analysis produced only three identifiable hazards for the operational activity of positioning the vehicle. As the operational activities were not further broken down into simpler tasks, the author was forced to think of the hazard possibilities at a very high level. This prevented visualization of the activity and/or task, resulting in only three hazards. This problem was further compounded when there were no explicit guidelines on how to assess the hazards for each task using the 5-M factor method. On the other hand, the author was able to generate 67 different failure causes for the same operational activity, using PFMECA. The detailed task decomposition, combined with the logical hazard analysis flow, allowed the author to identify hazards more effectively. Therefore, for step 3, generating hazards, the PFMECA technique was more thorough.

The structure of the PFMECA analysis process allowed for a more comprehensive analysis of each hazard, otherwise known as failure mode in PFMECA. Furthermore, the PFMECA worksheet states the thought process to be used for deriving the risk levels. For example, the author analyzed the failure to secure sufficient area for the operational activity for both RAW and PFMECA techniques. This generated risks RAW.1 for RAW analysis, and PFMECA.1 and PFMECA.2 for the PFMECA analysis. RAW.1 was brief and unclear. It stated the hazard as insufficient space cordoned off to carry out the work process. However, it did not explain the thought process that should be used to derive the hazard. It did not show what would have caused the hazard, nor did it show the consequences. Where RAW.1 was brief and unclear, the author was able to generate two risks through PFMECA, namely PFMECA.1 and PFMECA.2. In each of the PFMECA risks, the cause of risk, the effects of risk, and the current control measures were clearly stated next to the identified risk. Since every failure could be easily traced back to the specific failure mode and cause, it made administering remedial actions and monitoring efforts easier and more direct. Furthermore, the detailed analysis report provides a helpful reference and educational tool about the activity that junior officers would be leading.

For step 4, access hazard risk levels, the author was better able to differentiate and prioritize the risks with PFMECA as it utilizes RPN instead of generic risk matrices. The example RAW classified most of the risks as high. In fact, 21 out of 25 hazards were HIGH risks. On the other hand, the PFMECA failure causes had RPNs that were spread out across the range of 9 to 480. The analyst would have an easier time prioritizing these risks.

E. SUGGESTED REMEDIAL ACTIONS

Of the 12 failure causes that had an RPN of greater than 400, time constraints imposed on the task had the highest contribution to the top failure causes, followed by insufficient training and/or exposure (see Table 15). This is logical because the work tempo within the logistics bases, especially the armored fighting vehicle maintenance bases, is normally high. This is generally due to staffing issues, relatively high breakdown rates, and tedious maintenance tasks. Therefore, time to turnaround vehicles quickly enough to meet operational and training needs constrains the maintenance crew.

Table 15. Breakdown of the Failure Causes with an RPN above 400.

Failure causes	Quantity
Time constraints, leading to rushing or skipping steps	5
Insufficient training and/or exposure, leading to judgment errors or forgetting steps	5
Wrong interpretation and execution as a result of confusion during coordination from miscommunication	1
Distractions	1

Table 16 shows some preliminary remedial actions to mitigate the identified risks based on the safety manuals, training safety regulations, and the past lessons learnt archives available in the SAF. In general, there is a compelling need to provide additional time for any maintenance activity, the need to conduct just-in-time refresher training demonstrations and briefings emphasizing the need to be careful and deliberate, and to enforce supervision of all the critical operational activities.

More research into human reliability analysis and systems safety needs to be done to develop a research-backed remedial action plan for the risks identified. This is not within the scope of this thesis.

Table 16. Recommended Remedial Actions

Failure causes	**Remedial Action**
Time constraints, leading to rushing or skipping steps	1. Plan for sufficient time for activity 2. Emphasize the danger of rushing through 3. Emphasize on the importance of proper technique 4. Enforce supervision by squad leader
Insufficient training and/or exposure, leading to judgment errors or forgetting steps	1. Pre-activity brief and demonstration 2. More training to be conducted 3. Enforce supervision by squad leader
Wrong interpretation and execution as a result of confusion during coordination from miscommunication	1. Ensure proper training 2. Enforce supervision by squad leader
Distractions (leading to skipping of steps)	Enforce double checks by squad leader

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VI. CHOOSING SECONDARY RISK ASSESSMENT METHOD

One of the objectives of this thesis is to study the feasibility of adopting alternate methods to identify the potential for human error. In addition to employing a method familiar to the SAF, the author applied a Human Reliability Analysis (HRA) method to examine whether it is better than the RAW and/or the PFMECA analysis. Therefore, this section reviews a Human Reliability Analysis (HRA) method.

A. COMPARISON OF HRA TECHNIQUES

Human reliability analysis is closely linked to reliability engineering and has become seamlessly integrated into the safety engineering domain it supports (Boring 2012). Like risk assessment techniques, there are an abundance of techniques available. In fact, there are as many as 72 potential HRA methods and tools available (Bell and Holroyd 2009). However, Bell and Holroyd's study pointed out that very few methods are fully developed, in widespread use, suitable for generic use, and validated by research studies.

There is no known HRA method currently utilized in the SAF to guide this author to a method for examination in this thesis. Therefore, the author developed a set of criteria to scope the selection of a suitable HRA method. This set included the following:

- fully developed and under widespread use across multiple industries
- open access to assessment method
- generic (non-nuclear industry specific)
- preferably validated and proven by research studies
- simple and easy to learn and execute

First generation methods were considered fully developed. Although second generation methods attempt to improve upon first generation methods by incorporating contextual effects to capture the complexities surrounding human failures (French et al. 2011, 753), they are still considered as under development (Bell and Holroyd 2009).

In the same study by Bell and Holroyd, it was determined that there are four key first-generation HRA methods openly available for public use, as shown in Table 17. They are the Technique for Human Error Rate Prediction (THERP), the Accident Sequence Evaluation Program (ASEP), the Human Error Assessment and Reduction Technique (HEART), and the Simplified Plant Analysis Risk Human Reliability Assessment (SPAR-H).

Table 17. Key First Generation HRA Methods with Open Access

HRA Method	**Applicable Domain**
THERP	Nuclear with wider applications
ASEP	Nuclear
HEART	Generic
SPAR-H	Nuclear with wider applications

ASEP was determined to be a nuclear-specific tool and was not suitable for this work process. Table 18 shows a comparison of the advantages and disadvantages for the remaining HRA methods.

Table 18. Comparison of THERP, HEART, and SPAR-H. Adapted from Bell and Holroyd (2009).

	Advantages	Disadvantages
THERP	- THERP is well used in practice - It has a powerful methodology that can be audited - It is founded on a database of information that is included in the THERP handbook	- ***THERP can be resource intensive*** and time consuming - ***It does not offer enough guidance*** on modeling scenarios and the impact of Error Producing Conditions (EPC) on task performance and Human Error Probabilities (HEP). HEP is defined as the probability of a human committing an error while performing a task. EPC are factors that could increase the probability of human errors. Some examples are unfamiliarity with task, time shortages to execute task, and poor feedback on performed task - The ***level of detail*** that is included in THERP may be excessive for many assessments
HEART	- A versatile, quick and simple human-reliability-calculation method, which also gives the user (whether engineer or ergonomist) suggestions on error reduction - Requires relatively limited resources to complete an assessment	- Error dependency modeling is not included - ***Requires greater clarity*** of description to assist users when discriminating between generic tasks and their associated EPCs; there is potential for two assessors to calculate very different HEPs for the same task - Lack of information about the extent to which tasks should be decomposed for analysis - Potential for double counting (some elements of EPCs are implicit in the task description) - ***Subjective nature*** of determining the assessed proportion of affect
SPAR-H	- A simple underlying model makes SPAR-H relatively easy to use and results are traceable - The EPCs included cover many situations where more detailed analysis is not required - The THERP-like dependence model can be used to address both subtask and event sequence dependence	- The degree of resolution of the EPCs may be ***inadequate for detailed analysis*** - ***No explicit guidance*** is provided for addressing a wider range of PSFs when needed, but analysts are encouraged to use more recent context developing methods if more detail is needed for their application, particularly as related to diagnosis errors - Although the authors checked the SPAH-H underlying data for consistency with other methods, the ***basis for selection of final values was not always clear*** - The method may not be appropriate where more realistic, detailed analysis of diagnosis errors is needed

Due to the need for a relatively resource-light and easy-to-use technique, the author dropped the THERP technique. HEART was a very quick and straightforward analysis technique. This technique helps the practitioner to receive suggestions that can possibly reduce the error occurrence; and it is highly flexible in applicability across domains and industries (Adhikari et al. 2009). In addition, the HEART technique could be incorporated easily into the entire risk analysis method. The HEART technique would be compatible with the work done by FFBD and FMECA for task decomposition. Moreover, Kirwan independently validated the HEART technique. It is one of the few techniques that has been independently validated (Kirwan et al. 1997, 17). Therefore, HEART was the appropriate selection for this thesis.

B. PERFORMING HEART TECHNIQUE ON IDENTIFIED WORK TASKS

To analyze the tasks, the HEART analysis technique involves identifying the most appropriate task description based on the reference list of generic tasks and the associated basic HEP. The HEART technique utilized the FFBD process. For each task, one must identify all applicable error producing conditions from the reference list and assign the associated multipliers to the HEP. One assigns each EPC a proportion of effect and calculates the corresponding assessed effect. The final HEP is calculated based on the product of the basic HEP and the sum-product of the assessed effects. Appendix C lists the detailed steps and reference lists.

Research for this thesis applied the HEART analysis technique to the replacement of one side of the tracks of an AFV in the workshop environment. As in the PFMECA analysis, the thesis author was the representative user performing the HEART analysis. Table 19 shows a worked example, with reference to task 3.3.2, drive track pin partly free. From the Generic Task table, the task for driving the track pin partly free is a fairly simple task that could be performed rather rapidly by a well-trained operator. Thus, an unreliability value of 0.12 was assigned. For the rest of the tasks, the author assessed level of complexity and assigned higher HEP values to tasks that require higher levels of comprehension and/or skill, such as driving the AFV and/or guiding the AFV. Next, the author selected all possible EPCs from the reference list of EPCs provided. The author

also considered any EPC that he deemed to affect the human operator, considered the proportion of effect for each EPC based on the specific context of the task, and gave a value based on expert judgment. For example, he assigned the highest assessed proportion of effect to the EPC of time shortage. The values range from zero to one. This is because time limitation would be more likely to force the soldier to rush through his actions, and this is deemed to cause errors with serious consequences. Thereafter, the assessed effect was calculated according to the following formula (Chandler et al. 2006).

$$Assessed\ Effect = \{(EPC\ Mulitplier - 1)\ (Assessed\ Proportion\ of\ Effect)\} + 1$$

The final HEP value for the specific task is the product of the generic task unreliability and the assessed effects of every EPC.

Table 19. Worked Example for HEART Analysis

Level3	Sub-tasks	Generic Task Unreliability	EPC	EPC (Multiplier)	Assessed Proportion of Effect	Assessed Effect	HEP
3.3.2	Drive track pin partly free	0.12	Unfamiliarity	17	0.01	1.16	0.92199141
			Time shortage	11	0.3	4	
			Misperception of risks	4	0.05	1.15	
			Inexperienced Personnel	3	0.1	1.2	
			Inadequate checking	3	0.05	1.1	
			Unreliable instruments	1.5	0.01	1.005	
			Physcial capabilities	1.4	0.2	1.08	
			Low loading	1.1	0.05	1.005	

Appendix C shows the fully worked HEART table. Again, there is no specific threshold value to decide where to place the most emphasis and focus. This depends on a multitude of factors, including an organization’s risk appetite, any industry standards, safety or even legal requirements, and any other factors like imposed quality control (Forrest 2016). Similarly, the author conducted a descriptive statistical analysis on the 47 HEART HEP values, created a cumulative frequency curve, and selected the top 25 percent of the values for subsequent analysis. As the number of HEART HEP outcomes

was much lower than the PFMECA RPN outcomes, a larger percentage was chosen to generate a sufficiently sized dataset for discussion in this thesis. Selecting a larger percentage would lead to a more meaningful comparison and discussion of the riskiest hazards identified by both PFMECA and HEART techniques.

Therefore, the top 10 riskiest tasks were selected for the purpose of this discussion. However, as two of the tasks had the same HEART HEP value of 0.8876, namely HEART.36 and HEART.37, they were counted as one in the selection. Therefore, effectively 11 tasks were selected.

Table 20 shows the top 11 riskiest tasks that were identified through the HEART analysis.

Table 20. Top 10 Human Errors Identified by HEART Technique

Process Steps, Names and Description						Human Error Probability (Nominal Unreliability Probability x Assessed Effect1 x Assessed Effect 2 …)	HEART ID	Rank
Level1	**Operational Activities**	**Level2**	**Operational Tasks**	**Level3**	**Sub-tasks**			
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	0.921991415	HEART.23	1
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	0.912083328	HEART.11	2
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	0.9030528	HEART.12	3
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	0.892710397	HEART.29	4
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	0.888269052	HEART.27	5
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	0.887639412	HEART.36	6
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	0.887639412	HEART.37	6
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	0.81563001	HEART.39	8
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	0.684288	HEART.1	9
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	0.669532798	HEART.28	10
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	0.66561264	HEART.33	11

C. DISCUSSION—HEART VS. RAW RESULTS

Key results of the HEART analysis show that the operational activities with the highest probability of failure are derived from the operational activities of breaking track, forming track, positioning track, positioning vehicle, joining track, disposing track, and securing area, as shown in Table 20.

For step 2 of the risk analysis process, task decomposition, HEART is more comprehensive than RAW because of the FFBD task decomposition used. The FFBD was used because the subsequent steps of classifying the task's basic HEP required the task to be in its simplest form for ease of classification. However, this was not a strong argument for the advantage of HEART over RAW as the HEART technique used the FFBD from the PFMECA analysis for the HEART task decomposition method.

For step 3, generate hazards, the HEART analysis is a more comprehensive approach in terms of considering the EPCs, when compared to RAW. With available reference lists of generic tasks and error producing conditions, the analyst was able to analyze the probability of human error for each task in a more in-depth manner than the approach used in RAW. For example, RAW identified four hazards for the operational activity of disposing tracks, namely RAW.22 to RAW.25. Three of these were human error-producing conditions specific to lifting the tracks. On the other hand, the HEART technique was able to generate eight human error-producing conditions. These were all derived from the reference list: "unfamiliarity" with task and context, time shortage, misperception of risks, inexperienced personnel, inadequate checking, impoverished information, physical capabilities or the lack thereof, and low loading.

Another advantage that HEART has over RAW in the hazard generation step is that HEART can consider all the listed human error-producing conditions together, combine these conditions, and assess the overall probability of a human committing an error for the specific task of lifting tracks. However, for RAW, there would be three separate risk levels. In this aspect, HEART provided the extra flexibility for the analyst to determine the overall riskiest operational task, and also the ability to zoom into the details when required.

For step 4, assess risk hazard level, the HEART technique also was better able to prioritize the risk levels associated with each task as it utilizes probabilistic assessment of the risk levels instead of generic risk matrices used in RAW. Twenty-one out of 25 hazards identified by RAW had HIGH risk. On the other hand, the 47 error probabilities produced by HEART analysis were spread out across a wide range (0.000404 to 0.922).

D. DISCUSSION—HEART VS. PFMECA RESULTS

Table 21 shows the comparison of the top operational tasks that were identified to be the most probable to generate the failures due to human error. The author listed the top riskiest tasks in PFMECA and grouped them according to their tasks. For example, the author grouped PFMECA.167 and PFMECA.168 together under their common task, 6.4.2, “Torque Nut.” The author then showed the corresponding HEART HEP and analysis results next to the PFMECA tasks.

Table 21 shows that all of the riskiest tasks identified by PFMECA were also identified by HEART. In fact, it could be seen that the riskiest tasks identified by PFMECA were also flagged as the most risky tasks in HEART. This shows that, in the context of this work process, both HEART and PFMECA were able to generate similar results, albeit through different hazard generation and assessment approaches. However, the different hazard generation and assessment approaches were the main reason why the PFMECA technique is more suited to the SAF. Table 21 also shows that the PFMECA technique allows the analyst, in this case the author, to parse through each task and list the failure modes, effects, and potential causes, and determine the overall risk for each of the potential causes. This is especially useful for the SAF, where the junior officers would be able to follow the thought process and understand clearly the hazards involved. The opposite is true for the HEART process. The thought process was not explicitly clear and apparent to a layman.

Table 21. Verification of FMECA-Identified Tasks using HEART.

Level3	Sub-tasks	Failure Mode ID	Potential Failure Mode	Failure Effects	Potential Causes of Failure	FMECA RPN	HEART HEP	HEART RANK	HEART EPC
2.3.5	Manipulate steering yokes	PFMECA .64	Failure of ground guide to provide proper guidance	Ground guides fail to provide correct instructions	Wrong interpretation and execution as a result of confusion during coordination from miscommunication	432	0.9030528	3	• Time shortage • Misperception of risks • Inexperienced Personnel • Inadequate checking • Unreliable instruments
3.3.2	Drive track pin partly free	PFMECA .99	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft as a result of poor securing	Time constraints leading to skipping the evaluation process	441	0.9219914 15	1	• Unfamiliarity • Time shortage • Misperception of risks • Inexperienced Personnel • Inadequate checking • Unreliable instruments • Physical capabilities • Low loading
3.3.2	Drive track pin partly free	PFMECA .102	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required.	Insufficient training leading to perceptual confusion	432			
3.3.2	Drive track pin partly free	PFMECA .105	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence,	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody	Insufficient training	432			

Level3	Sub-tasks	Failure Mode ID	Potential Failure Mode	Failure Effects	Potential Causes of Failure	FMECA RPN	HEART HEP	HEART RANK	HEART EPC
			insufficient strength)						
3.3.2	Drive track pin partly free	PFMECA .106	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody	Time constraints leading to rushed actions, causing misalignment errors	432			
3.3.8	Hit Shoe	PFMECA .113	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft as a result of poor securing	Time constraints leading to skipping the evaluation process	432	0.921991415	1	• Unfamiliarity • Time shortage • Misperception of risks • Inexperienced Personnel • Inadequate checking • Unreliable instruments • Physical capabilities • Low loading (Repeated task—Same as 3.3.2)
3.3.8	Hit Shoe	PFMECA .117	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required	Insufficient training	432			

Level3	Sub-tasks	Failure Mode ID	Potential Failure Mode	Failure Effects	Potential Causes of Failure	FMECA RPN	HEART HEP	HEART RANK	HEART EPC
3.3.8	Hit Shoe	PFMECA .120	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody	Insufficient training	432			
3.3.8	Hit Shoe	PFMECA .121	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody	Time constraints leading to misalignment error	432			
6.4.2	Torque nut	PFMECA .168	Failure to use a calibrated torque wrench	Nut not torqued to specified value	Time constraints leading to omission of checks	480	0.6656126 4	11	• Unfamiliarity • Time shortage • Misperception of risks • Inexperienced Personnel • Inadequate checking • Unreliable instruments
6.4.2	Torque nut	PFMECA .167	Failure to use a calibrated torque wrench	Nut not torqued to specified value	Distractions leading to failure to check	400			
8.2.2	Place track on sprocket	PFMECA .179	Failure to wait for vehicle to stop engine before	Uncoordinated movements from the vehicle may cause collision or	Insufficient training leading to skipping of steps	432	0.8876394 12	6	• Unfamiliarity • Time shortage • Misperception of risks • Inexperienced

Level3	Sub-tasks	Failure Mode ID	Potential Failure Mode	Failure Effects	Potential Causes of Failure	FMECA RPN	HEART HEP	HEART RANK	HEART EPC
			commencing task	crush injuries					Personnel • Inadequate checking • Impoverished information • Unreliable instruments • Physical capabilities • Low loading

One key difference between HEART and PFMECA is that HEART considers the risks based on the probability of human error for the task as a whole, while PFMECA generates the risks based on a single failure mode and cause in the context of the task. While HEART generated 47 human error probabilities, PFMECA generated 200 failure causes for analysis. With a single human error probability for each operational task, this significantly drives down the number of the results generated by the HEART technique and makes for an easier assessment and analysis. More importantly, the HEART technique produces the overall probability of human error from the combination of all possible error-producing conditions. On the other hand, the PFMECA generates single failure modes, which may be an oversimplification of human error probabilities.

VII. CASE STUDY

The previous chapters of the thesis demonstrated the pros and cons of the RAW, modified PFMECA, and HEART methodologies to evaluate all AFV track replacement tasks. This chapter uses these RAW, PFMECA, and HEART analysis results to determine whether any of these methodologies would pick up the hazards and causes of hazards that led to an actual prior workshop incident documented by the SAF as a case study. Appendix D shows the workshop incident case study. With this comparison, the author then determined the effectiveness of each of the analysis techniques for this case study. At this point, it would be premature to generalize the results of this case study to include applicability to all other cases.

A. BRIEF SUMMARY OF WORKSHOP INCIDENT

The case study described technicians performing the work process to remove one side of an AFV track. At the time of the incident, the technician was using a sledgehammer to hit the drift pin to remove a track pin from the AFV's track. The track pin was about 75 percent driven out of its socket. During one of the last few swings of the sledgehammer to hit the drift pin, the technician misjudged the swing and missed the drift pin. As the swing momentum was not stopped by the drift pin and the friction between the track pin and its socket, the technician's swing momentum brought his hand to hit the sprocket wheel teeth located in the full swing path. As a result, he suffered crush injuries that caused partial deformity and broken nail on his right index finger.

The case study attributed the cause to the technician's eagerness to expedite the task for the impending audit. He rushed through the task, causing himself to misjudge and injure himself. The exact motivation behind his eagerness to complete the task was not immediately revealed in this case study. Hence, it would be speculative to focus on comparing his motivation as the failure cause. Therefore, the examination of this case study focuses on the failure cause of "rushing through the task," which would provide a clearer basis of comparison.

B. COMPARISON OF RAW, PFEMCA, AND HEART

Using the RAW analysis, the author failed to single out the task of removing the drift pin from the track of the AFV. Table 22 shows the RAW analysis associated with breaking track. The closest task was breaking track, which encompassed a large range of tasks. Hence, the supervisor, in this case a junior officer, would find it difficult to determine which task required closer supervision or more detailed reminders to the technician executing the task.

Table 22. RAW Analysis Result (Execution Phase)

B. Execution Phase	**Hazard ID**	**Identify Hazards (5-M Method)**	**Severity**	**Probability**	**Risk Level**
Break Track	RAW.9	Man. Poor communication between personnel working together	Critical	Likely	High
	RAW.10	Man. Inadequate skillset for the task	Critical	Occasional	High
	RAW.11	Man. Under stress to complete the task quickly	Critical	Occasional	High
	RAW.12	Man. Reckless attitude	Critical	Occasional	High
	RAW.13	Management. Insufficient rest time in between activities	Critical	Occasional	High
	RAW.14	Machine. Vehicle may malfunction	Critical	Seldom	Medium

Under the broad task of breaking track, the RAW technique was able to identify the described cause to a certain degree of accuracy. The case study described that the technician was too eager to complete the task for the impending audit. He rushed through the task, causing himself to misjudge and injure himself. The cause of his eagerness to complete the task for the impending audit was not described. In addition, there might have been other possible contributors to this accident. For example, his supervisor might have exerted pressure on him to expedite the task execution, someone could have distracted him for that instant, or his mind could have been distracted by problems at

home. However, this thesis does not focus on determining other possible contributors.[1] This event had a common denominator, which was an imposed time constraint, either self-imposed or imposed by the audit schedule, that motivated the technician's rushed actions. The closest explanation was RAW.11. RAW.11 describes the hazard as one of the 5-M factors, "Man," where the personnel at risk could be under a time constraint and, hence, stressed to complete the task quickly.

PFMECA analysis was able to identify the case study incident described. Through task decomposition, PFMECA was able to identify the specific task, "remove track pin from used track shoes," and its specific subtask 3.3.2, "Drive track pin partly free." Table 23 shows the PFMECA analysis of the said sub-task. These are the same RPN and ranking values created in the original analysis. The analysis further broke down the potential failure modes into five different causes, one of which properly described the case study workshop incident. This was listed as "Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength or time constraint)." The associated failure effect was "crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody." In the case study, the technician hit himself.

Table 23. PFMECA Analysis of Subtask 3.3.2

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**Potential Causes of Failure**	**RPN**	**Rank**
PFMECA.97	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft as a result of poor securing	Loosely secured sledgehammer head to shaft due to wear and tear and/or damage	90	135
PFMECA.98	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft as a result of poor securing	Inexperience leading to failure to carry out evaluation	378	19

[1] This analysis is based on the written case study available. Any inaccuracies or misinterpretations inherent in the case study would be reflected in the analysis performed in this section. It is not the intent of this thesis to examine the flaws of this case study, but rather to match the case study results with PFMECA, HEART, and RAW.

Failure Mode ID	Potential Failure Mode	Failure Effects	Potential Causes of Failure	RPN	Rank
PFMECA.99	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft as a result of poor securing	Time constraints leading to skipping the evaluation process	441	2
PFMECA.100	Weakened structural integrity of drift Pin and/or socket	Failure of the drift pin due to material stress defect, resulting in the shattering of the drift pin upon impact with sledgehammer	Material stress fatigue of drift Pin and/or socket	63	161
PFMECA.101	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required	Negligence or overconfidence	360	23
PFMECA.102	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required	Insufficient training leading to perceptual confusion	432	3
PFMECA.103	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required	Reduced alertness from insufficient sleep and/or rest	144	102
PFMECA.104	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody	Negligence or overconfidence	360	23

Failure Mode ID	Potential Failure Mode	Failure Effects	Potential Causes of Failure	RPN	Rank
PFMECA.105	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody	Insufficient training	432	3
PFMECA.106	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody	Time constraints leading to rushed actions, causing misalignment errors	432	3
PFMECA.107	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody	Reduced psychomotor coordination from insufficient sleep and/or rest	144	102
PFMECA.108	Failure to keep clear of the track shoe and sledgehammer trajectories	Crush injuries sustained	Inexperience leading to failure to recognize potential hazards	144	102

PFMECA analysis was also able to identify the cause of failure for this sub-task to a certain degree. Using the PFMECA technique, the author identified the following potential failure causes:

- negligence and/or overconfidence
- insufficient training
- time constraints leading to rushed actions causing misalignment errors
- reduced psychomotor coordination from insufficient sleep and/or rest

The PFMECA analysis was able to identify the described cause with a certain degree of accuracy. Similar to that described earlier, time constraints shaped the behavior of the technician. Therefore, PFMECA was able to identify the failure cause of the time constraints leading to rushed actions causing misalignment errors.

Furthermore, PFMECA analysis assigned four of the failure causes associated with the “Drive track pin partly free” sub-task to RPN values greater than 400, ranking them among the top risks. Among them, the failure cause of time constraints had an RPN value of 432.

When HEART analysis utilized the same task decomposition method, it was able to identify the task involved in the case study incident. In addition, the HEART analysis also singled out the sub-task as the riskiest task, with a probability of human error assessed at 0.92. Table 24 shows the HEART analysis for the sub-task. Evidently, time shortage was the biggest contributor to the final HEP value.

Table 24. HEART Analysis for Subtask 3.3.2

Category of Generic Task	Generic Task Unreliability	Error Producing Condition	Error Producing Condition	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
D	0.12	Unfamiliarity	17	0.01	1.16	0.92199141
	0.12	Time shortage	11	0.3	4	
	0.12	Misperception of risks	4	0.05	1.15	
	0.12	Inexperienced Personnel	3	0.1	1.2	
	0.12	Inadequate checking	3	0.05	1.1	
	0.12	Unreliable instruments	1.5	0.01	1.005	
	0.12	Physical capabilities	1.4	0.2	1.08	
	0.12	Low loading	1.1	0.05	1.005	

Both PFMECA and HEART analysis were effective in identifying both the task involved and the hazard. In addition, both methods were able to single out the task and/or hazard as one that stood out from the rest, allowing them to be isolated for targeted

remedial actions. On the other hand, RAW analysis was not able to identify the task involved. Although RAW analysis was able to identify the hazard involved, this might not have helped much because the supervisor would not know on which task he should prioritize his focus.

This case study showed that the PFMECA technique is easier than the HEART technique for the layman to follow and enables the layman to track the failure causes to the operational activity. This is especially important in the SAF where the majority of the supervisors are junior officers who may lack operational experience. With an easy-to-follow, comprehensive set of hazard analyses, the supervisor can appreciate and internalize better the full nuances of the work process and the hazards involved.

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VIII. RECOMMENDATION

The RAW technique is a useful risk assessment technique for the SAF as it is applicable across all scenarios, from training activities like physical proficiency tests to tactical operations in combat missions. This is because it is simple to understand and use, and it provides a quick method of assessing risks. This is advantageous in operations where planning and risk assessment times are constrained and leaders must quickly make risk assessments under dynamic conditions. Therefore, in such scenarios, PFEMCA and HEART analysis techniques are not viable as they are too time consuming. For other operations, such as maintenance work processes where surrounding conditions are static, and planning and risk assessment times are not constrained, the SAF would be better served by a more comprehensive alternative to reduce injury risks. A more comprehensive alternative has the potential to identify more hazards and allow for recommending and implementing appropriate mitigation control measures to enhance safety and minimize injuries in the organization.

Both the PFMECA and the HEART analysis methods were more effective than RAW in hazard risk analysis. In addition, both PFMECA and HEART were equally effective at identifying the top risks. However, PFMECA would be a more useful tool for SAF. This is because SAF is using the FMECA technique currently, a variant of the PFMECA technique. Hence, the incumbents in the organization would be familiar with the use of the tool.

The layout of the PFMECA template and the intuitive logic flow allows personnel using the PFMECA technique to easily learn and apply the technique. Furthermore, they can easily trace and follow the logic to deriving the results of the PFMECA. The reports generated through using PFMECA have a more logical flow and allow junior officers to understand fully the operational activity and the risks involved.

On the other hand, the HEART technique requires additional material like a Generic Task List and an EPC reference list to facilitate hazard analysis. The added requirement to understand the material may make the HEART technique difficult to

implement in the SAF due to tight training schedules and frequent rotation of new leaders. As such, the junior officers would have fewer barriers to overcome when using the PFMECA risk analysis tool.

PFMECA is also a flexible tool to adopt and apply to both technical systems. Many SAF operational activities include the close interaction of technical systems with human operators. While this thesis focuses on the human aspect of the operational activity, it is difficult to uncouple the technical systems from the human activities. Since the HEART analysis is not suitable to analyze technical systems, the PFMECA technique is preferred to achieve commonality of tools for hazard analysis of operational activities that require seamless integration of technical systems with human operators.

This research recommends that SAF embark on a one-time effort to select operations and work processes that are generally static. One area on which to focus would be maintenance work processes. Teams of subject matter experts could carry out a one-time risk assessment using PFMECA technique and promulgate the results as training safety regulations for all to reference. Singapore Armed Forces could continue using RAW as a secondary assessment method for leaders to assess the situation on the ground, right before the execution of work processes, for any new hazards that may arise due to changing conditions.

IX. CONCLUSION

PFMECA is a tried-and-tested technique for systematically deconstructing and identifying critical failure modes and causes in technical systems and manufacturing processes. This thesis applied the PFMECA technique to human work processes in the context of armored fighting vehicle maintenance and compared the results to those generated by a well-known HRA technique, HEART. In this context, the PFMECA was able to identify riskiest tasks within the work processes. However, a key shortcoming of the PFMECA was revealed when it could not identify the risks caused by a combination of failure causes and/or modes. Despite this, the PFMECA technique was able to identify a significant number of the risky tasks singled out by HEART for this work process.

When compared to the original RAW technique, PFMECA is a better way of forcing the practitioner to think through the entire process down to the individual task level and to visualize the possible failure modes and causes. Since the PFMECA is recommended to be conducted by a team of subject matter experts, the risk assessment report created by the subject matter experts would prove useful for the soldier on the ground. This is because the soldier on the ground is typically a drafted soldier with little or no prior exposure and limited experience, this comprehensive breakdown and analysis would be very useful for him to boost his knowledge and heighten is alertness. This is especially useful in an organization that is very sensitive to any safety lapses.

PFMECA is a tedious analysis method and would take considerable effort to complete. Therefore, it should be applied to work processes or activities that are generally static in nature. Furthermore, it would be most practical to conduct PFMECA as a one-time project and archive the results as templates for the future reference of all SAF leaders.

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X. FUTURE WORK

This thesis assumed that there would be minimal failures in the design of the technical system, and thus the risk analysis of the technical system would be outside the scope of this study. Future work could be done to further expand this study to include the failures at the component levels and the interactions between components and human actions.

This thesis was a feasibility study on the possibility of using PFMECA and HEART analysis techniques as an alternate primary assessment technique to identify risks. However, this was only compared with one case study. More extensive research needs to be done to further validate the results. Future work could be done to examine more accident case studies to ensure that the conclusions from this thesis are consistent with the results of the other case studies.

The PFMECA technique's key limitation in the context of this work process is that it focused on single failure modes rather than failure mode combinations. Future studies could attempt to find ways to improve the PFMECA technique to address this issue. One possible method would be to use this in conjunction with Hazard and Operability (HAZOP) study analysis. The HAZOP analysis is a generic analysis tool that is potentially easy to use and allows for analysis of failure mode combinations on top of single failure modes.

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APPENDIX A. OPERATIONAL ACTIVITY AND TASK DECOMPOSITION

Table 25 displays the operational activities and tasks involved in performing the work process of replacing one side of the AFV track, and the personnel required.

Table 25. Detailed Task Decomposition Table

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
1.0	Secure Area	1.1	Identify Area of Operations	Nil	Nil	Nil	Maintenance Section Commander	Personal Protective Equipment is assumed for all activities
		1.2	Cordon off area	Nil	Nil	Nil	2x Technicians	
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	Nil	1x Crew (Driver)	
				2.1.2	Open driver's hatch	Nil		
				2.1.3	Climb into driver's seat	Nil		
		2.2	Start Engine	2.2.1	Sound horn	Nil	1x Crew (Driver) 2x Technicians (Front & Rear Guides)	
				2.2.2	Select gear	Nil		Move gear selector to "Start"

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				2.2.3	Press "Start" Button	Nil		
				2.2.4	Check no warning lights	Nil		
		2.3	Drive vehicle into position	2.3.1	Release handbrake	Nil		
				2.3.2	Select gear	Nil		Move gear selector to "Drive"
				2.3.3	Sound horn	Nil		
				2.3.4	Manipulate brake and accelerator pedals	Nil		
				2.3.5	Manipulate steering yokes	Nil		
		2.4	Stop Vehicle	2.4.1	Manipulate brake and accelerator pedals	Nil		
				2.4.2	Select gear	Nil		Move gear selector to "Neutral"
		2.5	Stop Engine	2.5.1	Set handbrake	Nil		
				2.5.2	Turn off fuel control	Nil		

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				2.5.3	Turn off master power switch	Nil		
		2.6	Exit Vehicle	2.6.1	Climb out of driver's hatch	Nil	1x Crew (Driver)	
				2.6.2	Close driver's hatch	Nil		
				2.6.3	Climb down vehicle	Nil		
3.0	Break Track	3.1	Unstow track fixtures & drift pin	3.1.1	Climb onto top of vehicle	Nil	1x Technician	
				3.1.2	Remove track fixtures & drift pin	Nil		Pull out and lift up two rubber straps and remove the two track fixtures and drift pins
				3.1.3	Climb down from vehicle	Nil		
		3.2	Loosen track tension	3.2.1	Loosen bleed valve	5/8 inch open end wrench	1x Technician	Loosen but do not remove bleed valve on track adjuster and allow grease to flow out
				3.2.2	Check tension	Pencil		Place pencil between track and rear support roller. When pencil will fit between track and rear support roller but index finger will not, stop removing grease
				3.2.3	Tighten bleed valve	5/8 inch open end wrench		

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				3.2.4	Clean valve	Wiping rag		Wipe away spilled grease
		3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	3/4 inch drive T-bar handle 15/16 inch socket	Maintenance Section Commander 2x Technicians	Remove nut from track pin to be removed. The track pin to be removed will be those on every 7th track shoe
				3.3.2	Drive track pin partly free	Sledge Hammer Drift Pin		Drive track pin partly free with short end of drift pin
				3.3.3	Remove Drift pin	Nil		
				3.3.4	Drive track pin further out	Sledge Hammer Drift Pin		Drive track pin further out with medium end of drift pin
				3.3.5	Remove Drift pin	Nil		
				3.3.6	Drive track pin all the way out	Sledge Hammer Drift Pin		Drive track pin all the way out with long end of drift pin
				3.3.7	Remove Drift pin	Nil		Keep medium end up and remove drift pin
				3.3.8	Hit Shoe	Sledge Hammer		To break track, hit track shoe from inside of track
4.0	Position Vehicle	4.1	Enter Vehicle	4.1.1	Climb onto top of vehicle	Nil	1x Crew (Driver)	

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				4.1.2	Open driver's hatch	Nil		
				4.1.3	Climb into driver's seat	Nil		
		4.2	Start Engine	4.2.1	Sound horn	Nil	1x Crew (Driver) 2x Technicians (Front & Rear Guides)	
				4.2.2	Select gear	Nil		Move gear selector to "Start"
				4.2.3	Press "Start" Button	Nil		
				4.2.4	Check no warning lights	Nil		
		4.3	Drive vehicle into position	4.3.1	Release handbrake	Nil		
				4.3.2	Select gear	Nil		Move gear selector to "Reverse"
				4.3.3	Sound horn	Nil		
				4.3.4	Manipulate brake and accelerator pedals	Nil		
				4.3.5	Manipulate steering yokes	Nil		

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
		4.4	Stop Vehicle	4.4.1	Manipulate brake and accelerator pedals	Nil		
				4.4.2	Select gear	Nil		Move gear selector to “Neutral”
		4.5	Stop Engine	4.5.1	Set handbrake	Nil		
				4.5.2	Turn off fuel control	Nil		
				4.5.3	Turn off master power switch	Nil		
		4.6	Exit Vehicle	4.6.1	Climb out of driver’s hatch	Nil	1x Crew (Driver)	
				4.6.2	Close driver’s hatch	Nil		
				4.6.3	Climb down vehicle	Nil		
5.0	Dispose old track	5.1	Remove track pin (from OLD track shoes)	5.1.1	Remove nut from track pin	3/4 inch drive T-bar handle 15/16 inch socket	Maintenance Section Commander 2x Technicians	Remove nut from track pin to be removed. The track pin to be removed will be those on every 7th track shoe

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				5.1.2	Drive track pin partly free	Sledge Hammer Drift Pin		Drive track pin partly free with short end of drift pin
				5.1.3	Remove drift pin	Nil		
				5.1.4	Drive track pin further out	Sledge Hammer Drift Pin		Drive track pin further out with medium end of drift pin
				5.1.5	Remove drift pin	Nil		
				5.1.6	Drive track pin all the way out	Sledge Hammer Drift Pin		Drive track pin all the way out with long end of drift pin
				5.1.7	Remove drift pin	Nil		Keep medium end up and remove drift pin
				5.1.8	Hit shoe	Sledge Hammer		To break track, hit track shoe from inside of track
		5.2	Shift track links	5.2.1	Lift track links	Trolley	8x Technicians working in pairs	Lift OLD track links and track pins from ground
				5.2.2	Put onto trolley			
				5.2.3	Push trolley to work area			Push trolley to disposal cage
				5.2.4	Lift track links from trolley			Lift track links and track pins from trolley

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				5.2.5	Position track links			Lay track links and track pins onto pallets in disposal cage
6.0	Form Track	6.1	Shift track links	6.1.1	Lift track links	Trolley	8x Technicians working in pairs	Lift NEW track links and track pins from pallets (seven pieces of track shoes joined together)
				6.1.2	Put onto trolley			
				6.1.3	Push trolley to work area			Push trolley to front of vehicle
				6.1.4	Lift track links from trolley			Lift track links and track pins from trolley
				6.1.5	Position track links			Lay track links and track pins in one straight line in front of AFV road wheels
		6.2	Remove track pin (from NEW track shoes)	6.2.1	Remove nut from track pin	3/4 inch drive T-bar handle 15/16 inch socket	Maintenance Section Commander 2x Technicians	Remove nut from track pin to be removed. The track pin to be removed will be those on every 7th track shoe
				6.2.2	Drive track pin partly free	Sledge Hammer Drift Pin		Drive track pin partly free with short end of drift pin
				6.2.3	Remove Drift pin	Nil		
				6.2.4	Drive track pin further out	Sledge Hammer Drift Pin		Drive track pin further out with medium end of drift pin

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				6.2.5	Remove drift pin	Nil		
				6.2.6	Drive track pin all the way out	Sledge Hammer Drift Pin		Drive track pin all the way out with long end of drift pin
				6.2.7	Remove drift pin	Nil		Keep medium end up and remove drift pin
				6.2.8	Hit shoe	Sledge Hammer		To break track, hit track shoe from inside of track
		6.3	Join track shoes	6.3.1	Join two track links	Nil	8x Technicians working in pairs	Join two track links together - The track pin holes of the end of one track link should be aligned to that of the other track link
				6.3.2	Install track pin	Hammer		From inside of track, drive track pin into track pin hole
				6.3.3	Install nut on track pin	3/4 inch drive T-bar handle 15/16 inch socket		
		6.4	Torque nut	6.4.1	Mark nut for torquing	Nil	1x Technician	
				6.4.2	Torque nut	Torque wrench		

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
7.0	Position Vehicle	7.1	Enter Vehicle	7.1.1	Climb onto top of vehicle	Nil	1x Crew (Driver)	
				7.1.2	Open driver's hatch	Nil		
				7.1.3	Climb into driver's seat	Nil		
		7.2	Start Engine	7.2.1	Sound horn	Nil	1x Crew (Driver) 2x Technicians (Front & Rear Guides)	
				7.2.2	Select gear	Nil		Move gear selector to "Start"
				7.2.3	Press "Start" Button	Nil		
				7.2.4	Check no warning lights	Nil		
		7.3	Drive vehicle into position	7.3.1	Release handbrake	Nil		
				7.3.2	Select gear	Nil		Move gear selector to "Drive"
				7.3.3	Sound horn	Nil		

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				7.3.4	Manipulate brake and accelerator pedals	Nil		
				7.3.5	Manipulate steering yokes	Nil		
		7.4	Stop Vehicle	7.4.1	Manipulate brake and accelerator pedals	Nil		
				7.4.2	Select gear	Nil		Move gear selector to “Neutral”
		7.5	Stop Engine	7.5.1	Set handbrake	Nil		
				7.5.2	Turn off fuel control	Nil		
				7.5.3	Turn off master power switch	Nil		
		7.6	Exit Vehicle	7.6.1	Climb out of driver’s hatch	Nil	1x Crew (Driver)	
				7.6.2	Close driver’s hatch	Nil		
				7.6.3	Climb down vehicle	Nil		

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
8.0	Position Track (Initial)	8.1	Check track guide position	Nil	Nil	Nil	1x Technician	Check that track guides are centered in road wheel slots
		8.2	Guide track over Sprocket	8.2.1	Insert track pin	Nil	3x Technicians	Insert track pin part way into first track shoe hole
				8.2.2	Place track on sprocket	Crowbar		Lift track with crowbar and track pin and place it on sprocket
				8.2.3	Maintain track propped position	Crowbar		Lever crowbar against ground and track to hold track against sprocket. Remove track pin at end of activity
9.0	Position Vehicle	9.1	Enter Vehicle	9.1.1	Climb onto top of vehicle	Nil	1x Crew (Driver)	
				9.1.2	Open driver's hatch	Nil		
				9.1.3	Climb into driver's seat	Nil		
		9.2	Start Engine	9.2.1	Sound horn	Nil	1x Crew (Driver) 2x Technicians	

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				9.2.2	Select gear	Nil	(Front & Rear Guides)	Move gear selector to “Start”
				9.2.3	Press “Start” Button	Nil		
				9.2.4	Check no warning lights	Nil		
		9.3	Drive vehicle into position	9.3.1	Release handbrake	Nil		
				9.3.2	Select gear	Nil		Move gear selector to “Reverse”
				9.3.3	Sound horn	Nil		
				9.3.4	Manipulate brake and accelerator pedals	Nil		
				9.3.5	Manipulate steering yokes	Nil		
		9.4	Stop Vehicle	9.4.1	Manipulate brake and accelerator pedals	Nil		
				9.4.2	Select gear	Nil		Move gear selector to “Neutral”
		9.5	Stop Engine	9.5.1	Set handbrake	Nil		

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				9.5.2	Turn off fuel control	Nil		
				9.5.3	Turn off master power switch	Nil		
		9.6	Exit Vehicle	9.6.1	Climb out of driver's hatch	Nil	1x Crew (Driver)	
				9.6.2	Close driver's hatch	Nil		
				9.6.3	Climb down vehicle	Nil		
10.0	Position Track	10.1	Check track guide position	Nil	Nil	Nil	1x Technician	Check that track guides are centered in road wheel slots
		10.2	Guide track over Sprocket	10.2.1	Insert track pin	Nil	3x Technicians	Insert track pin part way into first track shoe hole
				10.2.2	Place track on sprocket	Crowbar		Lift track with crowbar and track pin and place it on sprocket
				10.2.3	Maintain track propped position	Crowbar		Lever crowbar against ground and track to hold track against sprocket. Remove track pin at end of activity
11.0	Join Track (while on vehicle)	11.1	Assemble Track fixtures	Nil	Nil	Track Fixtures	1x Technician	Position hooks same distance apart at ends of two track fixtures. Turn hex nuts to position hooks

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
		11.2	Install track fixtures	11.2.1	Move ends of track together	Crowbar	2x Technicians	Move ends of track together with crowbar
				11.2.2	Install track fixture on outside of track	Track Fixtures		Install track fixture on outside of track. Place hooks of track fixture in second track shoe slots
				11.2.3	Install track fixture on inside of track	Track Fixtures		Install track fixture on inside of track. Place hooks of track fixture in second track shoe slots
				11.2.4	Tighten track fixtures	1 3/8 inch open end wrench		Tighten two track fixtures evenly
				11.2.5	Check gap	6-inch ruler		Turn two hex nuts until ends of track are about 1/16 inch apart
		11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	Crowbar Sledge Hammer	2x Technicians	
				11.3.2	Insert drift pin	Sledge Hammer 1 3/8 inch open end wrench		Tap long end of drift pin through track pin holes to other side of track. Loosen or tighten track fixture as needed
				11.3.3	Maintain track pin hole alignment	Crowbar 6-inch ruler		Have helper hold track about 1 1/12 inches from track fixture using crowbar
				11.3.4	Install track pin	Hammer		From inside of track, install track pin in track pin hole. As helper aligns track pin holes with crowbar, lightly tap in track pin. Drive track pin all the way

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
								through track
				11.3.5	Install track pin nut	3/4 inch drive T-bar handle 15/16 inch socket		Install and tighten nut on track pin until one full thread shows on track pin
		11.4	Torque nut	11.4.1	Mark nut for torquing	Nil	1x Technician	
				11.4.2	Torque nut	Torque wrench		
		11.5	Remove track fixtures	11.5.1	Loosen track fixtures	1 3/8 inch open end wrench	1x Technician	Loosen two track fixtures with wrench
				11.5.2	Remove track fixtures	Nil		Remove two track fixtures
12.0	Adjust Track tension	12.1	Check track tension	Nil	Nil	Nil	1x Technician	Reach under bolt-on armor and try to turn rear support roller 1. If rear support roller does not turn freely, track is too loose 2. If rear support roller turns freely, try to pass index finger between track and rear support roller. If finger passes, track is too tight; else tension is okay and no adjustment needed
		12.2	Tighten track tension	12.2.1	Clean all dirt	Wiping rag	2x Technicians	Clean all dirt from grease fitting on track adjuster and grease gun nozzle

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
				12.2.2	Pump grease into track adjuster	Grease gun		Place grease gun nozzle on grease fitting, and pump grease into track adjuster
				12.2.3	Check track tension	Pencil		Place pencil between track and rear support roller. When pencil will fit between track and rear support roller but index finger will not, stop adding grease
				12.2.4	Clean valve	Wiping rag		Stop pumping grease, remove grease gun nozzle from grease fitting. Wipe away excess grease
		12.3	Loosen track tension	12.3.1	Loosen bleed valve	5/8 inch open end wrench	1x Technician	Loosen but do not remove bleed valve on track adjuster and allow grease to flow out
				12.3.2	Check tension	Pencil		Place pencil between track and rear support roller. When pencil will fit between track and rear support roller but index finger will not, stop removing grease
				12.3.3	Tighten bleed valve	5/8 inch open end wrench		
				12.3.4	Clean valve	Wiping rag		Wipe away spilled grease
13.0	Position Vehicle	13.1	Enter Vehicle	13.1.1	Climb onto top of vehicle	Nil	1x Crew (Driver)	
				13.1.2	Open driver's hatch	Nil		
				13.1.3	Climb into driver's seat	Nil		

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
		13.2	Start Engine	13.2.1	Sound horn	Nil	1x Crew (Driver) 2x Technicians (Front & Rear Guides)	
				13.2.2	Select gear	Nil		Move gear selector to “Start”
				13.2.3	Press “Start” Button	Nil		
				13.2.4	Check no warning lights	Nil		
		13.3	Drive vehicle into position	13.3.1	Release handbrake	Nil		
				13.3.2	Select gear	Nil		Move gear selector to “Drive”/”Reverse”
				13.3.3	Sound horn	Nil		
				13.3.4	Manipulate brake and accelerator pedals	Nil		
				13.3.5	Manipulate steering yokes	Nil		
		13.4	Stop Vehicle	13.4.1	Manipulate brake and accelerator pedals	Nil		
				13.4.2	Select gear	Nil		Move gear selector to “Neutral”

Level1 ID	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Tools Required	Personnel Required	Description
		13.5	Stop Engine	13.5.1	Set handbrake	Nil		
				13.5.2	Turn off fuel control	Nil		
				13.5.3	Turn off master power switch	Nil		
		13.6	Exit Vehicle	13.6.1	Climb out of driver's hatch	Nil	1x Crew (Driver)	
				13.6.2	Close driver's hatch	Nil		
				13.6.3	Climb down vehicle	Nil		

The following figures display the fully worked FFBD.

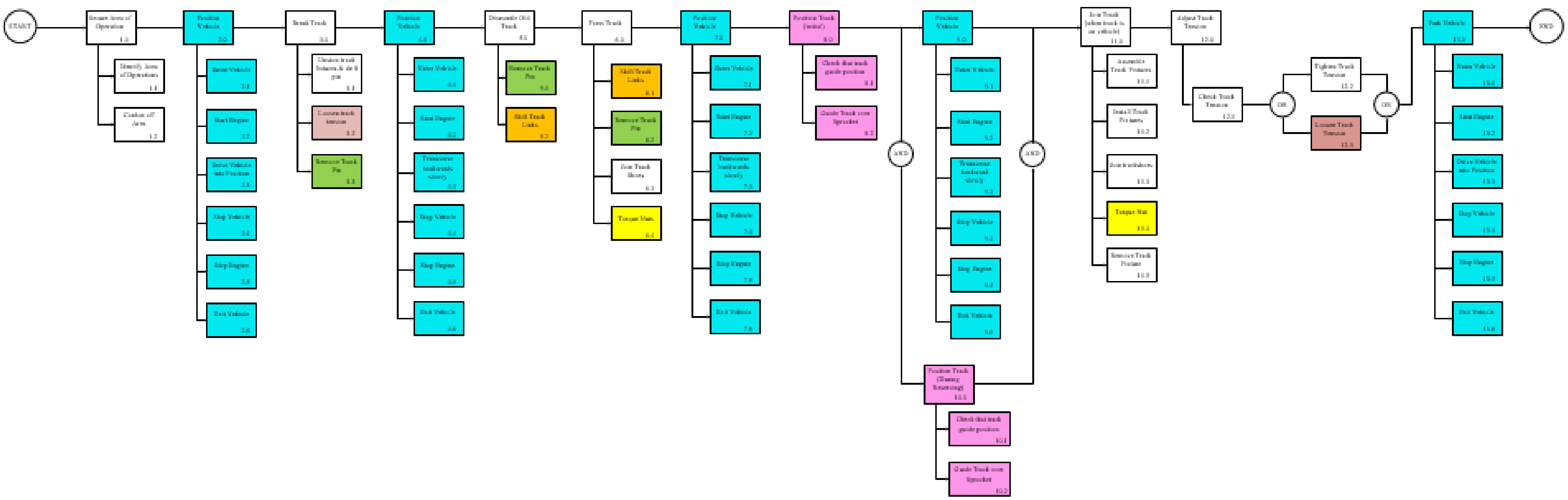

Figure 9. An Overall FFBD View of the Work Process.

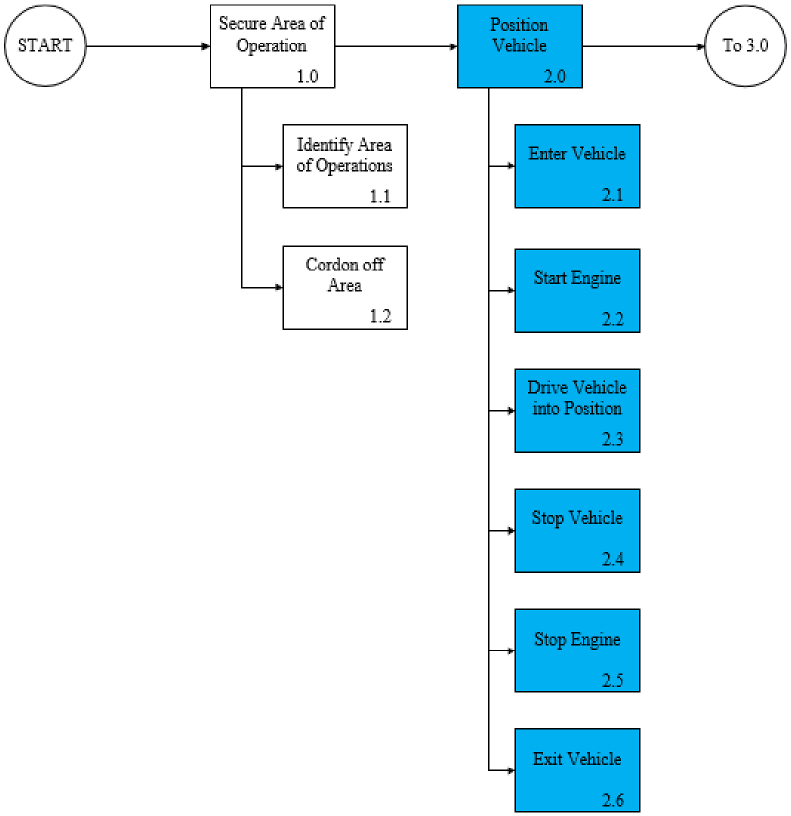

Figure 10. An Enlarged View of the Work Process FFBD (Phase 1)

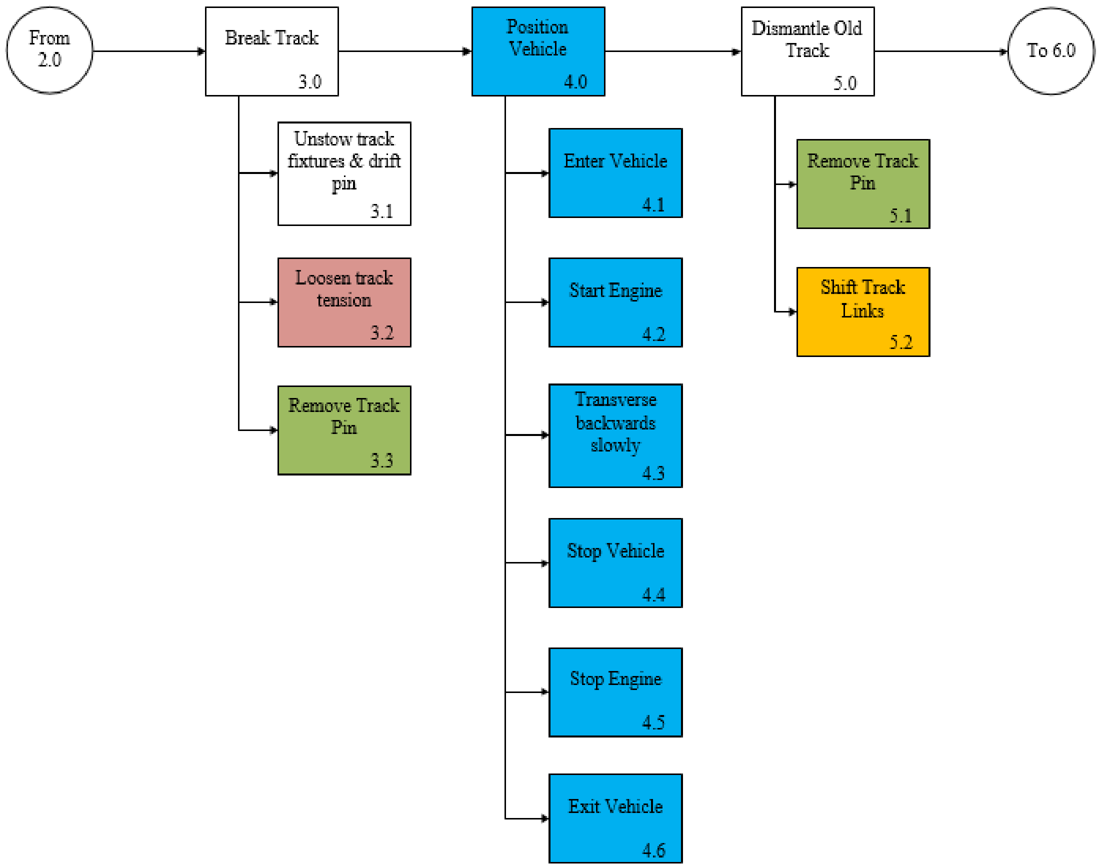

Figure 11. An Enlarged View of the Work Process FFBD (Phase 2).

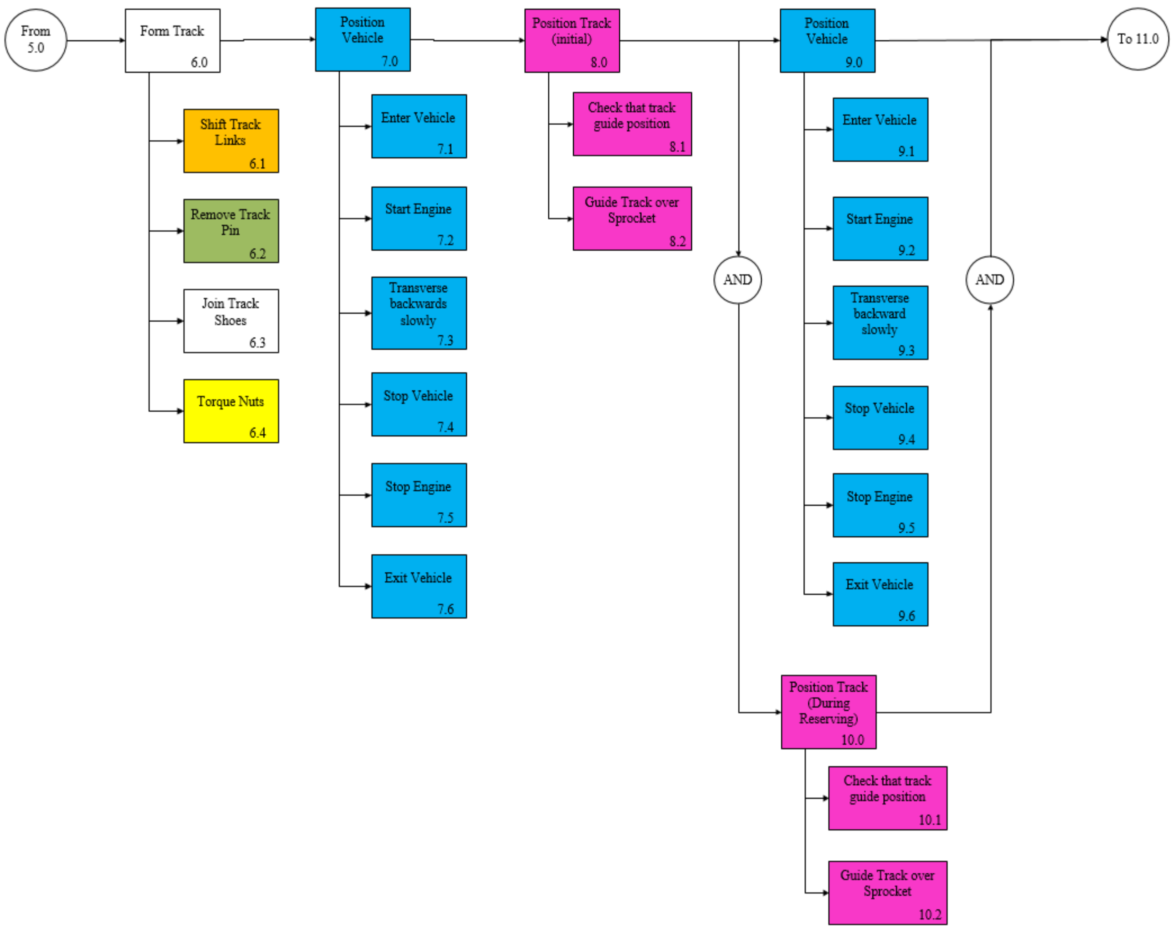

Figure 12. An Enlarged View of the Work Process FFBD (Phase 3).

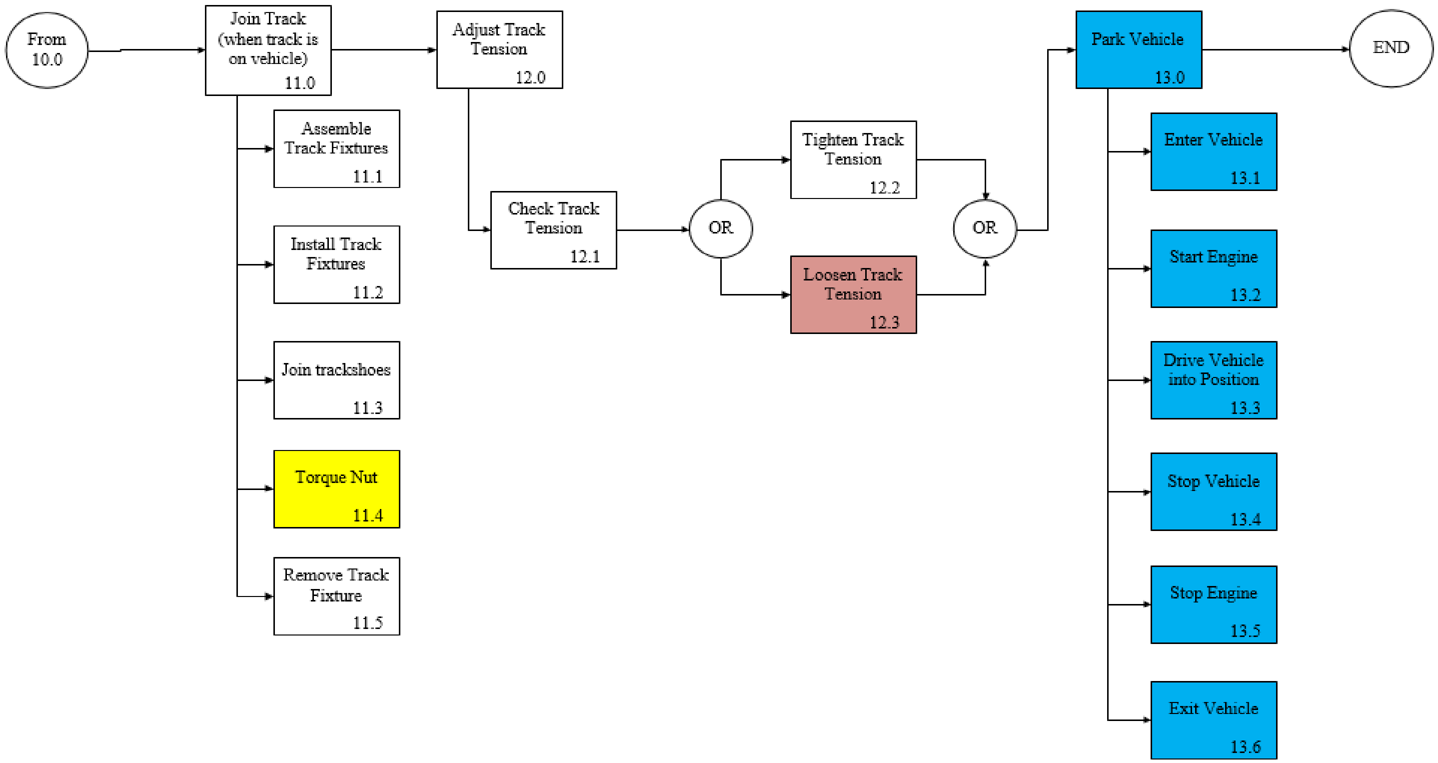

Figure 13. An Enlarged View of the Work Process FFBD (Phases 4 and 5).

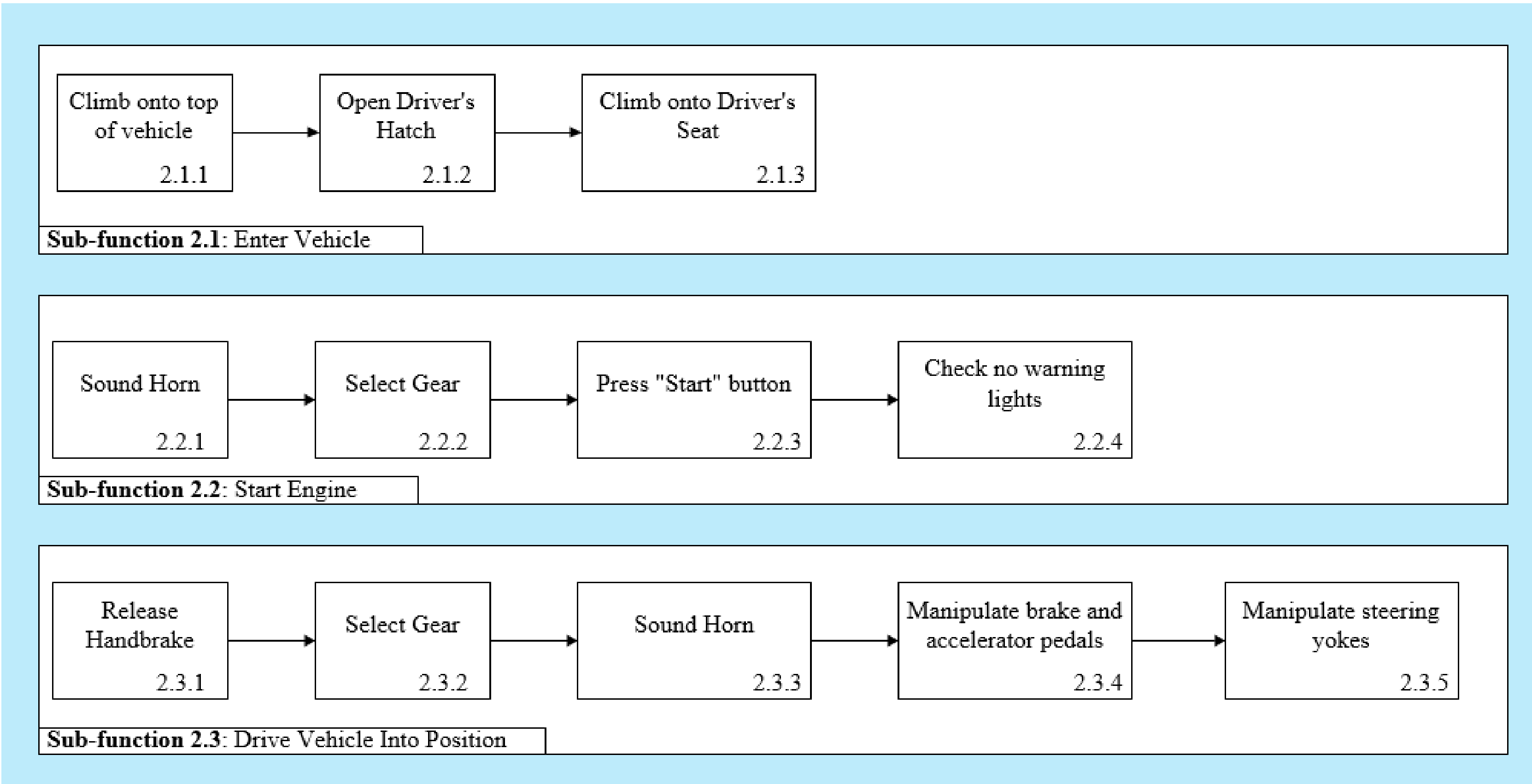

Figure 14. Subtasks Describing Subfunctions 2.1, 2.2, and 2.3, Respectively.

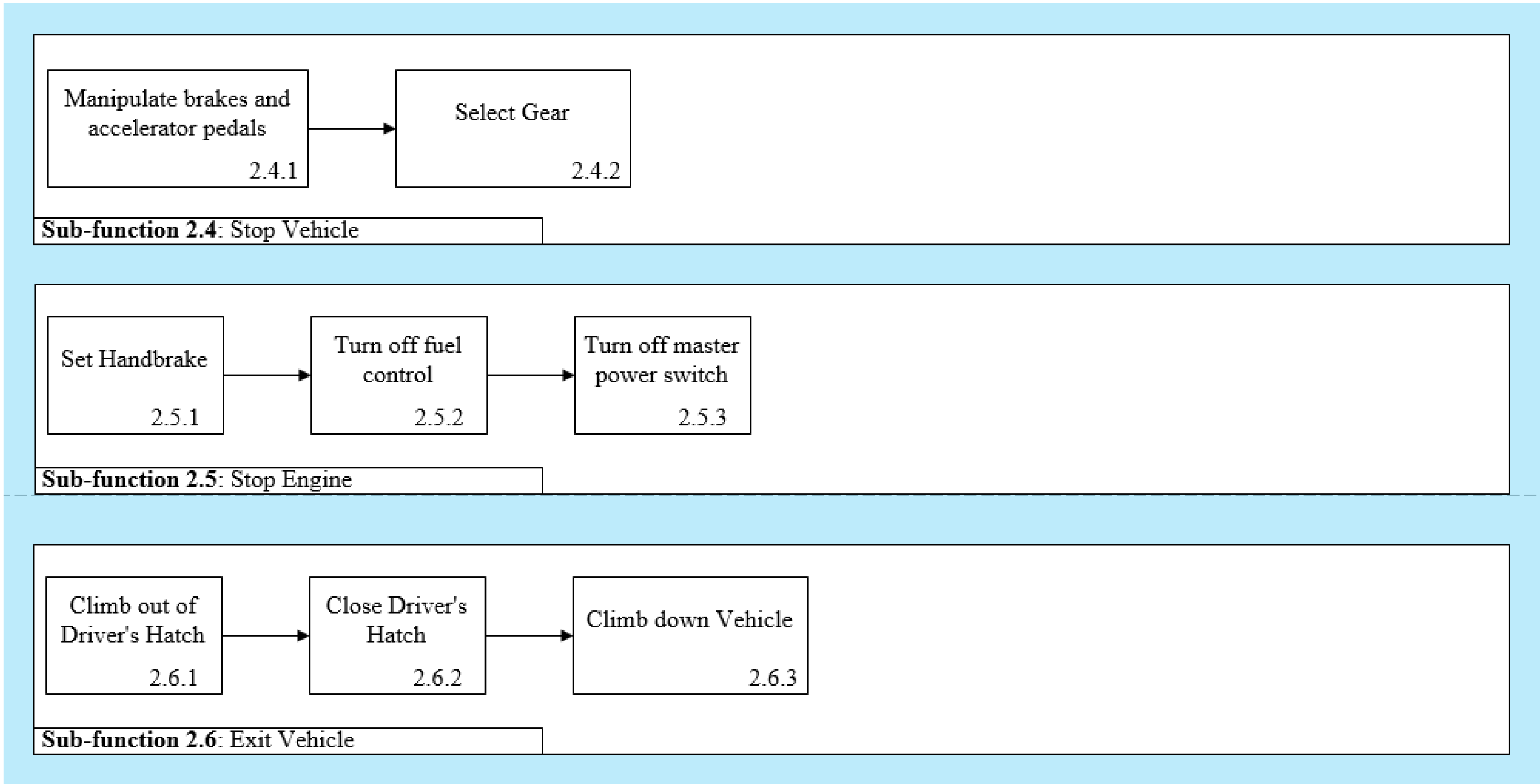

Figure 15. Subtasks Describing Subfunctions 2.4, 2.5, and 2.6, Respectively

With reference to Table 25, the subtasks are also relevant to subfunctions describing operational activities 2.0, 4.0, 7.0, 9.0, and 13.0.

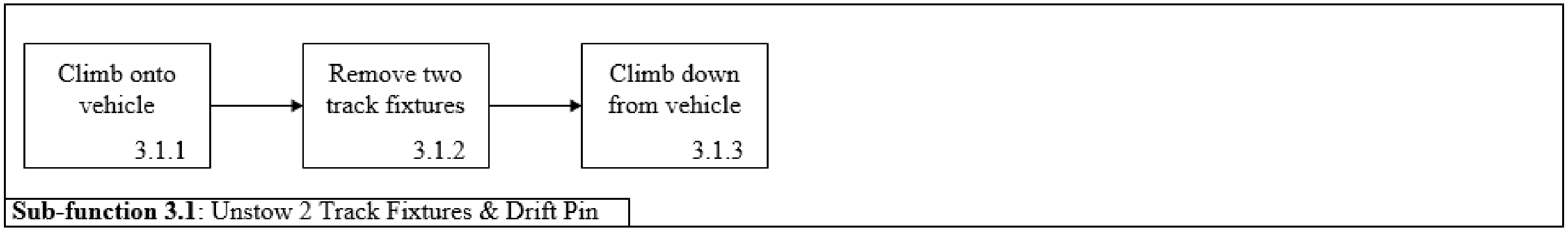

Figure 16. Subtasks Describing Subfunction 3.1.

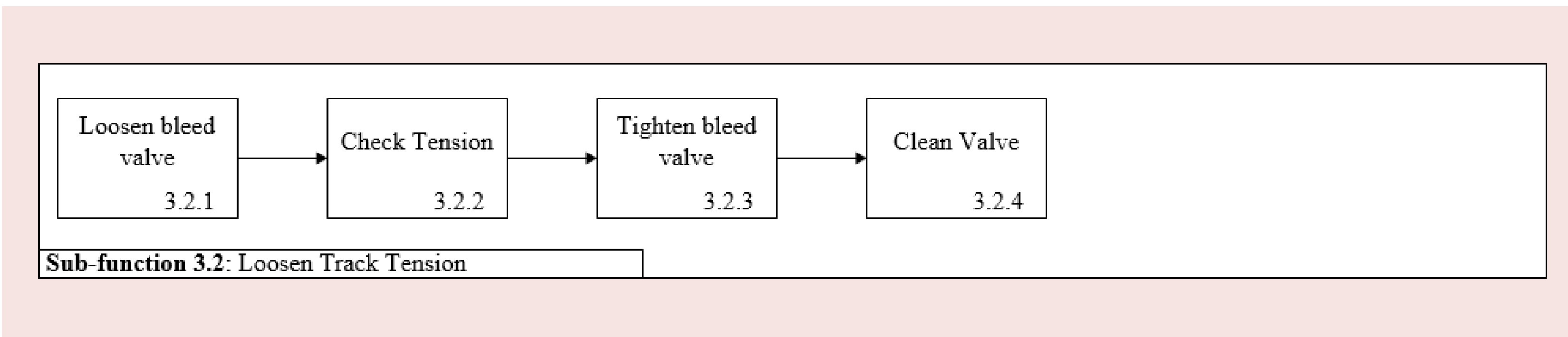

Figure 17. Subtasks Describing Subfunction 3.2.

With reference to Table 25, the subtasks are also relevant to subfunctions describing operational activity 13.3.

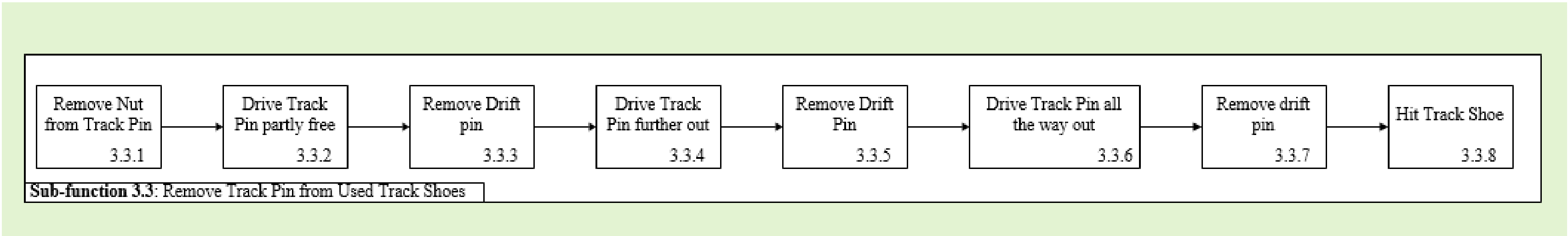

Figure 18. Subtasks Describing Subfunction 3.3.

With reference to Table 25, the subtasks are also relevant to subfunctions describing operational activities 5.1 and 6.2.

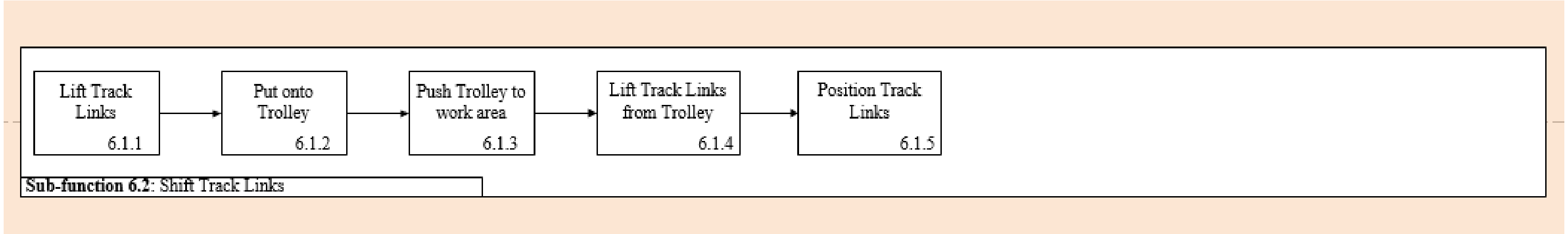

Figure 19. Subtasks Describing Subfunction 6.2.

With reference to Table 25, the subtasks are also relevant to subfunctions describing operational activity 7.1.

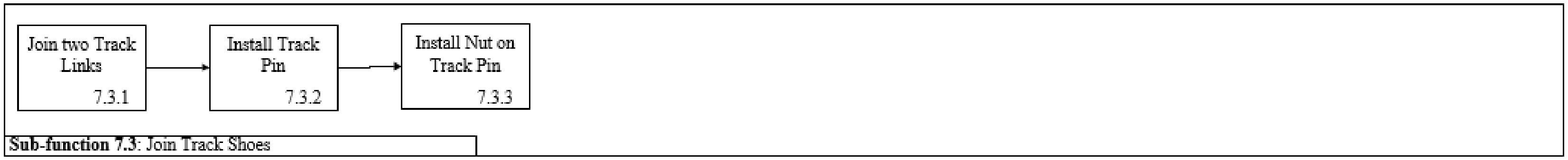

Figure 20. Subtasks Describing Subfunction 7.3.

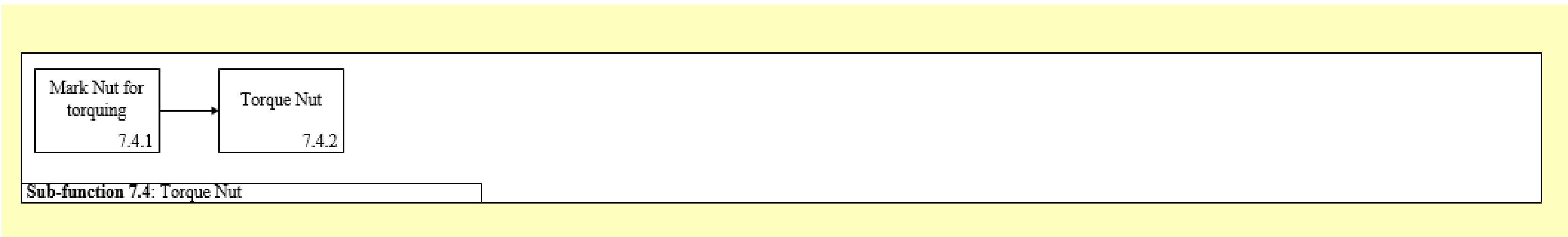

Figure 21. Subtasks Describing Subfunction 7.4.

With reference to Table 25, the subtasks are also relevant to subfunctions describing operational activity 11.4.

Figure 22. Subtasks Describing Subfunction 8.2.

With reference to Table 25, the subtasks are also relevant to subfunctions describing operational activity 10.2.

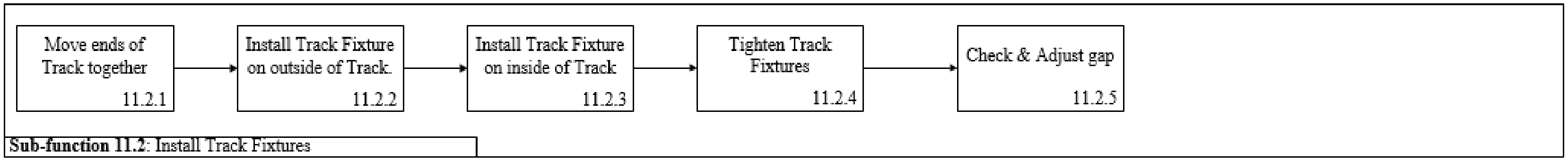

Figure 23. Subtasks Describing Subfunction 11.2.

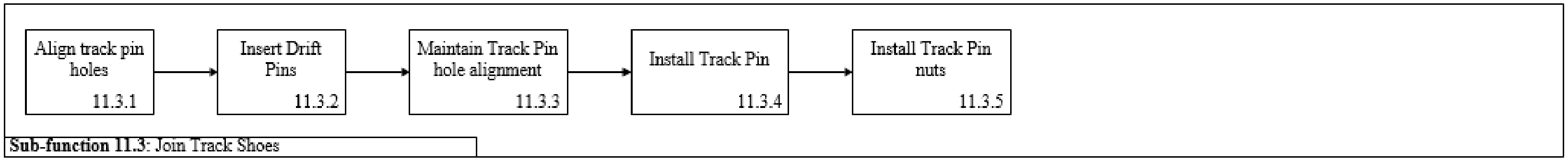

Figure 24. Subtasks Describing Subfunction 11.3.

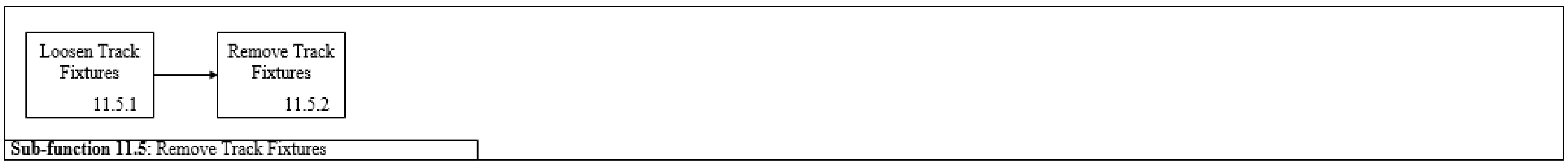

Figure 25. Subtasks Describing Subfunction 11.5.

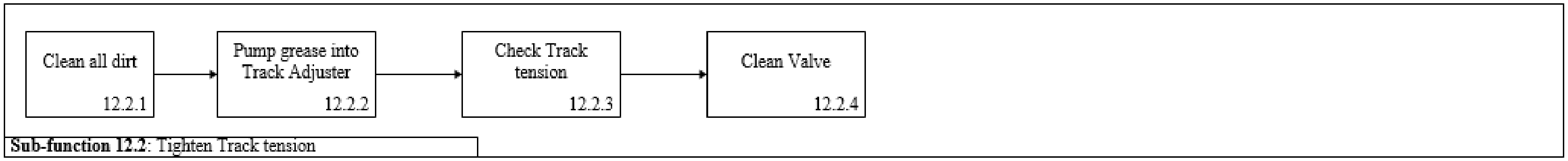

Figure 26. Subtasks Describing Subfunction 12.2.

APPENDIX B. WORKED PFMECA

This is the worked solution of the PFMECA for the stated work process of replacing a set of track links in the Armored Fighting Vehicle. The analysis result was too large to be displayed as one coherent table. Hence, it is broken down into two separate tables. Table 26 shows the operational activities and their corresponding list of PFMECA Identity numbers, called PFMECA.ID. Table 27 links the PFMECA.ID with the failure modes, effects, and criticality analysis. “Nil” entry in these tables mean that the previous task or operational activity had been decomposed to the simplest form. For example, in Table 26, there was no Level 3 sub-task for the “Identify Area of Operations (AO)” operational task because the author deemed that task to be at its simplest form for further analysis.

Table 26. Full List of Operational Activities and Corresponding PFMECA

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.1
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.2
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.3
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.4
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.5
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.6
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.7
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.8
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.9
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.10
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.11
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	PFMECA.12
1.0	Secure Area	1.2	Cordon off area	Nil	Nil	PFMECA.13
1.0	Secure Area	1.2	Cordon off area	Nil	Nil	PFMECA.14
1.0	Secure Area	1.2	Cordon off area	Nil	Nil	PFMECA.15

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	PFMECA.16
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	PFMECA.17
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	PFMECA.18
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	PFMECA.19
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.2	Open driver’s hatch	PFMECA.20
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.2	Open driver’s hatch	PFMECA.21
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.2	Open driver’s hatch	PFMECA.22
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.2	Open driver’s hatch	PFMECA.23
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.2	Open driver’s hatch	PFMECA.24
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.3	Climb into driver’s seat	PFMECA.25
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.3	Climb into driver’s seat	PFMECA.26
2.0	Position Vehicle	2.2	Start Engine	2.2.1	Sound horn	PFMECA.27
2.0	Position Vehicle	2.2	Start Engine	2.2.1	Sound horn	PFMECA.28

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
2.0	Position Vehicle	2.2	Start Engine	2.2.1	Sound horn	PFMECA.29
2.0	Position Vehicle	2.2	Start Engine	2.2.1	Sound horn	PFMECA.30
2.0	Position Vehicle	2.2	Start Engine	2.2.2	Select gear	PFMECA.31
2.0	Position Vehicle	2.2	Start Engine	2.2.2	Select gear	PFMECA.32
2.0	Position Vehicle	2.2	Start Engine	2.2.2	Select gear	PFMECA.33
2.0	Position Vehicle	2.2	Start Engine	2.2.2	Select gear	PFMECA.34
2.0	Position Vehicle	2.2	Start Engine	2.2.2	Select gear	PFMECA.35
2.0	Position Vehicle	2.2	Start Engine	2.2.3	Press "Start" Button	PFMECA.36
2.0	Position Vehicle	2.2	Start Engine	2.2.3	Press "Start" Button	PFMECA.37
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	PFMECA.38
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	PFMECA.39
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	PFMECA.40
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	PFMECA.41
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	PFMECA.42

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	PFMECA.43
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	PFMECA.44
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	PFMECA.45
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	PFMECA.46
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	PFMECA.47
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	PFMECA.48
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	PFMECA.49
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	PFMECA.50
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	PFMECA.51
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	PFMECA.52
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	PFMECA.53
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.54
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.55
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.56
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.57
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.58

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.59
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.60
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.61
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.62
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.63
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.64
2.0	Position Vehicle	2.5	Stop Engine	2.5.2	Turn off fuel control	PFMECA.65
2.0	Position Vehicle	2.5	Stop Engine	2.5.2	Turn off fuel control	PFMECA.66
2.0	Position Vehicle	2.5	Stop Engine	2.5.2	Turn off fuel control	PFMECA.67
2.0	Position Vehicle	2.5	Stop Engine	2.5.3	Turn off master power switch	PFMECA.68
2.0	Position Vehicle	2.5	Stop Engine	2.5.3	Turn off master power switch	PFMECA.69
2.0	Position Vehicle	2.5	Stop Engine	2.5.3	Turn off master power switch	PFMECA.70
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.1	Climb out of driver’s hatch	PFMECA.71

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.1	Climb out of driver’s hatch	PFMECA.72
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.1	Climb out of driver’s hatch	PFMECA.73
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.1	Climb out of driver’s hatch	PFMECA.74
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.2	Close driver’s hatch	PFMECA.75
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.2	Close driver’s hatch	PFMECA.76
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.2	Close driver’s hatch	PFMECA.77
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	PFMECA.78
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	PFMECA.79
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	PFMECA.80
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	PFMECA.81
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	PFMECA.82
3.0	Break Track	3.1	Unstow track fixtures & drift pin	3.1.2	Remove track fixtures & drift pin	PFMECA.83
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	PFMECA.84
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	PFMECA.85
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	PFMECA.86

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
3.0	Break Track	3.2	Loosen track tension	3.2.2	Check tension	PFMECA.87
3.0	Break Track	3.2	Loosen track tension	3.2.4	Clean valve	PFMECA.88
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	PFMECA.89
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	PFMECA.90
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	PFMECA.91
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	PFMECA.92
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	PFMECA.93
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	PFMECA.94
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	PFMECA.95
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	PFMECA.96
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.97
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.98
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.99
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.100

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.101
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.102
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.103
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.104
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.105
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.106
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.107
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.108
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.3	Remove drift pin	PFMECA.109
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.5	Remove drift pin	PFMECA.110
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.7	Remove drift pin	PFMECA.111
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.112
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.113
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.114
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.115

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.116
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.117
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.118
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.119
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.120
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.121
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.122
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit shoe	PFMECA.123
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.124
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.125
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.126
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.127
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.128
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.129

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.130
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.131
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.132
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.133
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.134
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.135
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.136
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	PFMECA.137
5.0	Dispose old track	5.2	Shift track links	5.2.2	Put onto trolley	PFMECA.138
5.0	Dispose old track	5.2	Shift track links	5.2.2	Put onto trolley	PFMECA.139
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	PFMECA.140
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	PFMECA.141
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	PFMECA.142

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	PFMECA.143
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	PFMECA.144
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	PFMECA.145
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	PFMECA.146
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	PFMECA.147
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	PFMECA.148
6.0	Form Track	6.3	Join track shoes	6.3.2	Install track pin	PFMECA.149
6.0	Form Track	6.3	Join track shoes	6.3.2	Install track pin	PFMECA.150
6.0	Form Track	6.3	Join track shoes	6.3.2	Install track pin	PFMECA.151
6.0	Form Track	6.3	Join track shoes	6.3.2	Install track pin	PFMECA.152
6.0	Form Track	6.3	Join track shoes	6.3.2	Install track pin	PFMECA.153
6.0	Form Track	6.3	Join track shoes	6.3.2	Install track pin	PFMECA.154
6.0	Form Track	6.3	Join track shoes	6.3.2	Install track pin	PFMECA.155
6.0	Form Track	6.3	Join track shoes	6.3.2	Install track pin	PFMECA.156
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	PFMECA.157
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	PFMECA.158

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	PFMECA.159
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	PFMECA.160
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	PFMECA.161
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	PFMECA.162
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	PFMECA.163
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	PFMECA.164
6.0	Form Track	6.4	Torque nut	6.4.1	Mark nut for torquing	PFMECA.165
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.166
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.167
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.168
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.169
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.170
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.171
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.172
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.173
8.0	Position Track (Initial)	8.1	Check track guide position	Nil	Nil	PFMECA.174
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.1	Insert track pin	PFMECA.175

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.1	Insert track pin	PFMECA.176
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.177
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.178
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.179
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.180
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.181
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.182
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.183
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.184
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	PFMECA.185
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	PFMECA.186
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	PFMECA.187
11.0	Join Track (while on vehicle)	11.1	Assemble Track fixtures	Nil	Nil	PFMECA.188
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	PFMECA.189
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.2	Install track fixture on outside of track	PFMECA.190
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	PFMECA.191
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	PFMECA.192
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	PFMECA.193

Level1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	Failure Mode ID
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	PFMECA.194
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.5	Check gap	PFMECA.195
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.2	Insert drift pin	PFMECA.196
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.3	Maintain track pin hole alignment	PFMECA.197
11.0	Join Track (while on vehicle)	11.5	Remove track fixtures	11.5.1	Loosen track fixtures	PFMECA.198
11.0	Join Track (while on vehicle)	11.5	Remove track fixtures	11.5.1	Loosen track fixtures	PFMECA.199
11.0	Join Track (while on vehicle)	11.5	Remove track fixtures	11.5.1	Loosen track fixtures	PFMECA.200

Table 27. Fully Worked Failure Modes, Effects, and Criticality Analysis for the Work Process

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 1	Failure to secure a sufficiently large AO for unimpeded operations	Lead to need for complicated maneuvers in order to execute work process, increasing	3	Space Limitation	5	Visual checks	6	90	135

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
		unfamiliarity and thus safety risks							
PFMECA. 2	Failure to secure a sufficiently large AO for unimpeded operations	Lead to need for complicated maneuvers in order to execute work process, increasing unfamiliarity and thus safety risks	3	Inexperience causing judgment error	6	Nil	5	90	135
PFMECA. 3	Failure to identify all possible hazards in the AO	Lead to increased exposure to safety risks when executing work process	5	Negligence or overconfidence	5	Nil	10	250	64
PFMECA. 4	Failure to identify all possible hazards in the AO	Lead to increased exposure to safety risks when executing work process	5	Inexperience causing failure to detect deterioration of situation/workplace	6	Nil	5	150	100
PFMECA. 5	Failure to identify all possible hazards in the AO	Lead to increased exposure to safety risks when executing work process	5	Failure to carry out task due to workload (slip the mind)	6	Nil	4	120	121

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 6	Failure to identify all possible hazards in the AO	Lead to increased exposure to safety risks when executing work process	5	Lack of training provided in identifying hazards	7	Nil	4	140	113
PFMECA. 7	Failure to take into account weather conditions	Working in and/or immediately after inclement weather will increase slip risks, lightning strike risks	8	Negligence or overconfidence	2	Nil	4	64	159
PFMECA. 8	Failure to take into account weather conditions	Working in and/or immediately after inclement weather will increase slip risks, lightning strike risks	8	Inexperience causing failure to carry out evaluation	6	Reference to meteorological station forecast	4	192	83
PFMECA. 9	Failure to take into account weather conditions	Working under hot weather may lead to heat exhaustion	7	Negligence or overconfidence causing failure to detect cues	2	Nil	6	84	146
PFMECA. 10	Failure to take into account weather conditions	Working under hot weather may lead to heat exhaustion	7	Inexperience causing failure to detect deterioration of situation	6	Observation of personnel Reference to meteorological station forecast Implementation of work-rest	2	84	146

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
						cycle			
PFMECA. 11	Failure to take into account crew fatigue levels	Reduced alertness and exhaustion may cause increased safety risks in work process execution	9	Negligence or overconfidence	2	Nil	6	108	130
PFMECA. 12	Failure to take into account crew fatigue levels	Reduced alertness and exhaustion may cause increased safety risks in work process execution	9	Inexperience in planning around work hours and intensity	6	Observation of personnel Reference to meteorological station nowcast Implementation of work-rest cycle	4	216	73
PFMECA. 13	Failure to erect prominent signage to prevent miscommuni-cation to external parties due to negligence and/or poor	Unexpected intrusions of external parties may expose both external parties and the work crew to safety risks	5	Negligence or overconfidence	2	Nil	6	60	162

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	planning								
PFMECA. 14	Failure to erect prominent signage to prevent miscommuni-cation to external parties due to negligence and/or poor planning	Unexpected intrusions of external parties may expose both external parties and the work crew to safety risks	5	Insufficient time due to workload	6	Nil	6	180	87
PFMECA. 15	Failure to erect prominent signage to prevent miscommuni-cation to external parties due to negligence and/or poor	Unexpected intrusions of external parties may expose both external parties and the work crew to safety risks	5	Inexperience leading to omission of activity	6	Observation of personnel by section commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest	4	120	121

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	planning					cycle (instituted process)			
PFMECA. 16	Failure to gain proper footing on latches	Fall from height (up to 2 meters), leading to fall injuries	9	Slippery footholds due to presence of water, oil, and/or grease	2	Manual inspection by crew (not an included process)	6	108	130
PFMECA. 17	Failure to gain proper footing on latches	Fall from height (up to 2 meters), leading to fall injuries	9	Time constraints leading to rushing of actions	6	Supervision by Section Commander (relies on vigilance)	5	270	55
PFMECA. 18	Failure to maintain balance on top of the vehicle	Fall from height (up to 2.6 meters), leading to fall injuries	9	Slippery surfaces due to presence of water, oil, and/or grease	2	Nil	6	108	130
PFMECA. 19	Entanglement of wearables (i.e., necklace, ring, loose clothing, bootlaces)	Impeded movement may cause loss of balance	8	Loose apparel	2	Nil	6	96	134
PFMECA. 20	Failure to have a proper grip on the hatch	Losing grip on hatch during opening. Hatch snapping back	8	Slippery hatch edge due to presence of water,	1	Nil	6	48	179

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
		may hit personnel, leading to hit injury		oil, and/or grease					
PFMECA. 21	Failure to have a proper grip on the hatch	Losing grip on hatch during opening. Hatch snapping back may hit personnel, leading to hit injury	8	Failure to wear PPE	7	Manual inspection by crew before work	1	56	167
PFMECA. 22	Failure to have a proper grip on the hatch	Losing grip on hatch during opening. Hatch snapping back may hit personnel, leading to hit injury	8	Improper grip	1	Supervision by Section Commander (detection is left to chance)	7	56	167
PFMECA. 23	**Failure to secure the hatch properly**	Open hatch not secured firmly to catch	8	Faulty catch	2	Equipment Serviceability checks prior to servicing	2	32	187
PFMECA. 24	**Failure to secure the hatch properly**	Open hatch not secured firmly to catch	8	Insufficient strength applied to the action of closing the hatch	2	Supervision by Section Commander (detection is not readily done)	8	128	118
PFMECA. 25	Failure to have controlled descent into the	Slip and fall into confined space with many sharp objects,	5	Slippery footholds due to presence of water, oil, and/or	3	Nil	6	90	135

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	driver's seat due to slippery steps	leading to cut and/or leg injuries		grease					
PFMECA. 26	Failure to have controlled descent into the driver's seat due to slippery steps	Slip and fall into confined space with many sharp objects, leading to cut and/or leg injuries	5	Insufficient lighting to illuminate the footholds	3	Nil	6	90	135
PFMECA. 27	**Failure of horn to sound**	Failure of horn to sound as demanded	9	Faulty electrical connection	1	Equipment Serviceability checks prior to servicing	1	9	197
PFMECA. 28	**Failure of horn to sound**	Failure of horn to sound as demanded	9	Inexperience leading to omission of activity	6	Supervision by Section Commander	2	108	130
PFMECA. 29	**Failure of horn to sound**	Failure of horn to sound as demanded	9	Insufficient practice leading to slippage in memory	5	Nil	8	360	23
PFMECA. 30	**Failure of horn to sound**	Failure of horn to sound as demanded	9	Negligence or overconfidence causing omission of activity	3	Supervision by Section Commander (relies on vigilance)	5	135	116
PFMECA. 31	**Failure of gear to engage correct gear**	Failure of correct gear to engage	9	Faulty gears	1	Detected through thorough	9	81	148

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
						inspection (not readily done)			
PFMECA. 32	**Failure of gear to engage correct gear**	Failure of correct gear to engage	9	Fatigue leading to execution error	3	Pre-activity checks Work-rest cycle	6	162	96
PFMECA. 33	**Failure of gear to engage correct gear**	Failure of correct gear to engage	9	Time constraints leading to rushing of actions	6	Supervision by Section Commander (relies on vigilance)	5	270	55
PFMECA. 34	**Failure of gear to engage correct gear**	Failure of correct gear to engage	9	Negligence or overconfidence	2	Failure cannot be readily detected until it is too late (i.e., vehicle is observed to be moving in wrong direction)	9	162	96
PFMECA. 35	**Failure of gear to engage at all**	Failure of gear to engage	1	Faulty gears	1	Detected through thorough inspection (not readily done)	9	9	197
PFMECA. 36	**Failure of vehicle to start**	Failure of vehicle to start	1	Faulty electrical connection	1	Detected through thorough	9	9	197

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
						inspection (not readily done)			
PFMECA. 37	**Failure of vehicle to start**	Failure of vehicle to start	1	Faulty Ignition	1	Detected through thorough inspection (not readily done)	9	9	197
PFMECA. 38	**Failure to identify all warning lights**	Warning Lamps not working	9	Faulty electrical connection	1	Detected through thorough inspection (not readily done)	9	81	148
PFMECA. 39	**Failure to identify all warning lights**	Personnel fails to register warning lights	9	Too much ambient lighting	1	Nil	6	54	172
PFMECA. 40	**Failure to identify all warning lights**	Personnel fails to register warning lights	9	Negligence or overconfidence	3	Nil	6	162	96
PFMECA. 41	**Failure to identify all warning lights**	Personnel fails to register warning lights	9	Time constraints leading to rushing of actions	6	Nil	6	324	38
PFMECA. 42	**Failure to identify all warning lights**	Personnel fails to register warning lights	9	Interruptions and distractions leading to loss of concentration	5	Nil	6	270	55
PFMECA. 43	**Failure to identify all**	Personnel fails to register warning	9	Insufficient training	2	Only licensed crew can	3	54	172

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
	warning lights	lights				operate the vehicle (100% inspection)			
PFMECA. 44	**Failure to identify all warning lights**	Personnel fails to register warning lights	9	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel Reference to meteorological station nowcast Implementation of work-rest cycle	4	144	102
PFMECA. 45	**Failure of handbrakes to release**	Handbrakes fail to release	9	Faulty hydraulic pumps	1	Detected through thorough inspection (not readily done)	9	81	148
PFMECA. 46	**Failure of handbrakes to release**	Handbrakes fail to release	9	Rusty and/or stiff brake calipers	1	Detected through thorough inspection (not readily done)	9	81	148
PFMECA. 47	**Failure of handbrakes to release**	Handbrakes fail to release	9	Time constraints leading to rushing of actions	6	Nil	6	324	38
PFMECA. 48	**Failure of handbrakes to release**	Handbrakes fail to release	9	Interruptions and distractions leading to loss of concentration	5	Nil	6	270	55

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 49	**Failure of handbrakes to release**	Handbrakes fail to release	9	Insufficient training	2	Only licensed crew can operate the vehicle (100% inspection)	3	54	172
PFMECA. 50	**Failure of handbrakes to release**	Handbrakes fail to release	9	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel Reference to meteorological station nowcast Implementation of work-rest cycle	4	144	102
PFMECA. 51	Failure to work accelerator pedals properly	Unable to move vehicle smoothly	9	Time constraints leading to rushing of actions	6	Nil	6	324	38
PFMECA. 52	Failure to work accelerator pedals properly	Unable to move vehicle smoothly	9	Driver's height limitation	2	Limitation would be sieved out during training course	1	18	189
PFMECA. 53	Failure to work accelerator pedals properly	Unable to move vehicle smoothly	9	Insufficient training	5	Only licensed crew can operate the vehicle (100% inspection)	3	135	116
PFMECA. 54	**Failure of steering yokes to engage due**	Steering yokes fail to engage	9	Faulty transmission	1	Detected through thorough	9	81	148

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	to transmission					inspection (not readily done)			
PFMECA. 55	Failure to heed ground guides' instructions	Driver fails to follow ground guide's instructions	9	Miscommunication with ground guides due to different lingo (signals) used leading to different interpretations	2	All personnel are taught a single set of signals (as specified in SAF training manual) Automatic identification through Crew and/or ground guides	2	36	184
PFMECA. 56	Failure to heed ground guides' instructions	Driver fails to follow ground guide's instructions	9	Miscommunication with ground guides due to reduced alertness from lack of sleep	5	Observation of personnel Reference to meteorological station nowcast Implementation of work-rest cycle	2	90	135
PFMECA. 57	Failure to heed ground guides' instructions	Driver fails to follow ground guide's instructions	9	Driver's height limitation leading to insufficient field of view to see ground guide	2	Limitation would be sieved out during training course	1	18	189

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 58	Failure to heed ground guides' instructions	Driver fails to follow ground guide's instructions	9	Negligence or overconfidence causing a failure to double check	4	Nil	6	216	73
PFMECA. 59	Failure of ground guide to provide proper guidance	Ground guides fail to provide correct instructions	9	Miscommunication with ground guides due to different lingo (signals) used, leading to different interpretations	2	All personnel are taught a single set of signals (as specified in SAF training manual) Automatic identification through crew and/or ground guides	2	36	184
PFMECA. 60	Failure of ground guide to provide proper guidance	Ground guides fail to provide correct instructions	9	Wrong signals used due to insufficient training	5	Supervision by Section Commander (detection is not readily done)	6	270	55
PFMECA. 61	Failure of ground guide to provide proper guidance	Ground guides fail to provide correct instructions	9	Wrong judgment on the part of ground guides due to inexperience	7	Supervision by Section Commander (detection is not readily done)	6	378	19

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 62	Failure of ground guide to provide proper guidance	Ground guides fail to provide correct instructions	9	Wrong judgment on the part of ground guides due to reduced cognitive function from heat exhaustion	5	Supervision by Section Commander (detection is not readily done)	6	270	55
PFMECA. 63	Failure of ground guide to provide proper guidance	Ground guides fail to provide correct instructions	9	Wrong judgment on the part of ground guides due to reduced cognitive function from fatigue	7	Supervision by Section Commander (detection is not readily done)	6	378	19
PFMECA. 64	Failure of ground guide to provide proper guidance	Ground guides fail to provide correct instructions	9	Wrong interpretation and execution as a result of confusion during coordination from miscommunication	8	Supervision by Section Commander (detection is not readily done)	6	432	3
PFMECA. 65	Failure to turn off fuel control	Excessive exhaust may cause asthmatic personnel to suffer attacks	7	Time constraints leading to rushing of actions causing omission of activity	2	Exhaust will be spewed. This is observable. But detection is based on double checks and relies on vigilance	5	70	158

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 66	Failure to turn off fuel control	Excessive exhaust may cause asthmatic personnel to suffer attacks	7	Insufficient training leading to slippage of mind and causing omission of activity	1	Exhaust will be spewed. This is observable. But detection is based on double checks and relies on vigilance	5	35	186
PFMECA. 67	Failure to turn off fuel control	Excessive exhaust may cause asthmatic personnel to suffer attacks	7	Reduced alertness from insufficient sleep and/or rest	4	Exhaust will be spewed. This is observable. But detection is based on double checks and relies on vigilance	5	140	113
PFMECA. 68	**Failure of master power switch to engage**	Failure of master power switch to engage	9	Loose / faulty electrical connections	1	Engine will be emitting sound. This is observable. But detection is based on double checks and relies on vigilance	5	45	181
PFMECA. 69	**Failure of master power switch to**	Failure of master power switch to engage	9	Insufficient training leading to slippage of mind	1	Engine will be emitting sound. This is	5	45	181

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	engage			and causing omission of activity		observable. But detection is based on double checks and relies on vigilance			
PFMECA. 70	**Failure of master power switch to engage**	Failure of master power switch to engage	9	Reduced alertness from insufficient sleep and/or rest	4	Engine will be emitting sound. This is observable. But detection is based on double checks and relies on vigilance	5	180	87
PFMECA. 71	Failure to have controlled ascent out of driver's seat	Slip and fall into confined space with many sharp objects, leading to cut and/or leg injuries	5	Slippery footholds due to presence of water, oil, and/or grease	2	Manual inspection by crew (not an included process)	6	60	162
PFMECA. 72	Failure to have controlled ascent out of driver's seat	Slip and fall into confined space with many sharp objects, leading to cut and/or leg injuries	5	Time constraints leading to rushing of actions	6	Nil	6	180	87
PFMECA. 73	Failure to have controlled ascent out of	Slip and fall into confined space with many sharp objects,	5	Overconfidence leading to skipping of steps beyond	7	Nil	6	210	76

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	driver's seat	leading to cut and/or leg injuries		physical capability					
PFMECA. 74	Failure to have controlled ascent out of driver's seat	Slip and fall into confined space with many sharp objects, leading to cut and/or leg injuries	5	Insufficient lighting to illuminate the footholds	3	Manual inspection by crew (not an included process)	6	90	135
PFMECA. 75	Failure to maintain balance	Getting hit may cause a loss of balance and lead to fall from heights	8	Using too much strength (judgment error) due to inexperience	1	No checks	10	80	153
PFMECA. 76	Failure to maintain balance	Getting hit may cause a loss of balance and lead to fall from heights	8	Losing grip while exerting force due to not wearing PPE	1	No checks	10	80	153
PFMECA. 77	Failure to remove hands in time	Crushed fingers due to failure to close driver's hatch in a controlled manner, causing the hatch's downward momentum to crush the personnel's fingers between the hatch cover and hatch opening.	9	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel Reference to meteorological station nowcast Implementation of work-rest cycle	4	144	102

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 78	Failure to gain proper footing on latches due to slippery footholds causing personnel to slip and fall from height	Fall from height (up to 2 meters), leading to fall injuries	8	Slippery footholds due to presence of water, oil, and/or grease	3	Manual inspection by crew (not an included process)	6	144	102
PFMECA. 79	Failure to gain proper footing on latches due to slippery footholds causing personnel to slip and fall from height	Fall from height (up to 2 meters), leading to fall injuries	8	Slippery surfaces due to presence of water, oil, and/or grease	3	Manual inspection by crew (not an included process)	6	144	102
PFMECA. 80	Poor landing techniques	Fall from height (up to 2.6 meters), leading to fall injuries like twisted ankle or knee injuries	5	Insufficient training leading to act performed wrongly	3	Training is provided to all personnel	1	15	192
PFMECA. 81	Poor landing techniques	Fall from height (up to 2.6 meters), leading to fall injuries like twisted	5	Fatigue leading to execution error	6	Pre-activity checks Work-rest cycle	6	180	87

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		ankle or knee injuries							
PFMECA. 82	Poor landing techniques	Fall from height (up to 2.6 meters), leading to fall injuries like twisted ankle or knee injuries	5	Slippery surfaces due to presence of water, oil, and/or grease	2	Manual inspection by crew (not an included process)	6	60	162
PFMECA. 83	Slippage due to poor grip	Injury to hand	2	Improper grip	1	Supervision by Section Commander (detection is not readily done)	6	12	193
PFMECA. 84	Worn valve grooves	Failure to loosen bleed valve due to worn valve grooves	7	Worn valve grooves due to wear and tear	6	Manual inspection by crew (not an included process)	6	252	61
PFMECA. 85	Weakened structural integrity of opened ended wrench	Failure to loosen bleed valve due to overload failure of open ended wrench	7	Material stress fatigue of open ended wrench	1	Manual inspection by crew (not an included process)	7	49	175
PFMECA. 86	Direct skin contact with grease	Dermatological diseases due to skin contact with	4	Allergic reaction from direct skin contact with grease	2	No known process to check for	10	80	153

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
		discharged grease				chemical allergies in personnel			
PFMECA. 87	Failure to check correct tension	Incorrect tension	6	Insufficient experience	3	Double checks by commander	5	90	135
PFMECA. 88	Direct skin contact with grease	Dermatological diseases due to skin contact with discharged grease	4	Allergic reaction from direct skin contact with grease	2	No known process to check for chemical allergies in personnel	10	80	153
PFMECA. 89	Worn valve grooves	Failure to loosen bleed valve due to worn valve grooves	7	Worn valve grooves due to wear and tear	6	Manual inspection by crew (not an included process)	6	252	61
PFMECA. 90	Weakened structural integrity of drive T-bar and/or socket due to material stress fatigue	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the	7	Material stress fatigue of open ended wrench	1	Manual inspection by crew (not an included process)	7	49	175

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)							
PFMECA. 91	Failure to fit socket fully into the nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Time constraints leading to rushed actions, causing misalignment errors	6	Manual inspection by crew / section commander (not an included process)	6	252	61

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 92	Failure to fit socket fully into the nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Insufficient training leading to misalignment errors	3	Supervision by Section Commander (detection is not readily done)	8	168	94
PFMECA. 93	Failure to fit socket fully into the nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the	7	Inexperience leading to failure to detect error	6	Nil	8	336	29

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)							
PFMECA. 94	Failure to fit socket fully into the nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or	7	Reduced alertness from insufficient sleep and/or rest leading to execution error	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle (instituted process)	4	112	123

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		fractures)							
PFMECA. 95	Application of too much force	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Insufficient training leading to too much force used	6	Supervision by Section Commander (relies on vigilance)	5	210	76

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 96	Application of too much force	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Reduced alertness from insufficient sleep and/or rest	6	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle (instituted process)	4	168	94
PFMECA. 97	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft as a result of poor securing	9	Loosely secured sledgehammer head to shaft due to wear and tear and/or damage	2	Manual inspection and double checks but not automated	5	90	135
PFMECA. 98	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being	9	Inexperience leading to failure to carry out	6	Manual inspection	7	378	19

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		dislodged from the shaft as a result of poor securing		evaluation					
PFMECA. 99	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft as a result of poor securing	9	Time constraints, leading to skipping the evaluation process	7	Supervision by Section Commander (detection is not readily done)	7	441	2
PFMECA. 100	Weakened structural integrity of Drift Pin and/or socket	Failure of the drift pin due to material stress defect, resulting in the shattering of the drift pin upon impact with sledgehammer	9	Material stress fatigue of drift pin and/or socket	1	This type of cause cannot be detected	7	63	161
PFMECA. 101	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required.	9	Negligence or overconfidence	4	This type of cause cannot be detected	10	360	23
PFMECA. 102	Failure to understand sledgehammer weight	Strain injuries sustained due to unfamiliarity with sledgehammer	9	Insufficient training leading to perceptual confusions	6	Supervision by Section Commander (detection is not	8	432	3

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	characteristics and the swinging actions required	weight characteristics and the swinging actions required.				readily done)			
PFMECA. 103	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required.	9	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle (instituted process)	4	144	102
PFMECA. 104	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Negligence or overconfidence	4	This type of cause cannot be detected	10	360	23

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 105	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Insufficient training	6	Supervision by Section Commander (detection is not readily done)	8	432	3
PFMECA. 106	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Time constraints leading to rushed actions, causing misalignment errors	6	Nil	8	432	3
PFMECA. 107	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Reduced psychomotor coordination from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast	4	144	102

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
						Implementation of work-rest cycle (instituted process)			
PFMECA. 108	Failure to keep clear of the track shoe and sledgehammer trajectories	Crush injuries sustained	9	Inexperience leading to failure to recognize potential hazards	2	Nil	8	144	102
PFMECA. 109	Slippage due to poor grip	Injury to hand	2	Improper grip	1	Supervision by Section Commander (detection is not readily done)	5	10	194
PFMECA. 110	Slippage due to poor grip	Injury to hand	2	Improper grip	1	Supervision by Section Commander (detection is not readily done)	5	10	194
PFMECA. 111	Slippage due to poor grip	Injury to hand	2	Improper grip	1	Supervision by Section Commander (detection is not readily done)	5	10	194

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 112	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft, as a result of poor securing	9	Loosely secured sledgehammer head to shaft due to wear and tear and/or damage	2	Manual inspection and double checks but not automated	5	90	135
PFMECA. 113	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft, as a result of poor securing	9	Time constraints leading to skipping the evaluation process	6	Nil	8	432	3
PFMECA. 114	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft, as a result of poor securing	9	Overconfidence leading to ignoring observations	3	Nil	8	216	73
PFMECA. 115	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft, as a result of poor securing	9	Inexperience leading to failure to carry out evaluation	6	Manual inspection	7	378	19
PFMECA. 116	Failure to understand sledgehammer weight	Strain injuries sustained due to unfamiliarity with sledgehammer	9	Negligence or overconfidence	4	This type of cause cannot be detected	10	360	23

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	characteristics and the swinging actions required	weight characteristics and the swinging actions required.							
PFMECA. 117	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required.	9	Insufficient training	6	Supervision by Section Commander (detection is not readily done)	8	432	3
PFMECA. 118	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required.	9	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle (instituted process)	4	144	102

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 119	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Negligence or overconfidence	4	This type of cause cannot be detected	10	360	23
PFMECA. 120	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Insufficient training	6	Supervision by Section Commander (detection is not readily done)	8	432	3
PFMECA. 121	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Time constraints leading to misalignment error	6	Nil	8	432	3

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 122	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Reduced psychomotor coordination from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle (instituted process)	4	144	102
PFMECA. 123	Failure to keep clear of the track shoe and sledgehammer trajectories	Crush injuries sustained	9	Inexperience leading to failure to recognize potential hazards	2	Nil	5	90	135
PFMECA. 124	Failure to maintain proper lifting posture	Back injuries sustained	7	Lack of training leading to wrong posture	7	Training is provided to all personnel	1	49	175
PFMECA. 125	Failure to maintain proper lifting posture	Back injuries sustained	7	Negligence or overconfidence	7	Supervision by Section Commander (reliance on vigilance)	5	245	65

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 126	Failure to maintain proper lifting posture	Back injuries sustained	7	Repetitive actions leading to efficiency-thoroughness-trade-offs (i.e., taking shortcuts)	7	Supervision by Section Commander (reliance on vigilance)	5	245	65
PFMECA. 127	Failure to maintain proper lifting posture	Back injuries sustained	7	Time constraints causing skipping of steps	6	Nil	8	336	29
PFMECA. 128	Failure to maintain proper lifting posture	Back injuries sustained	7	Insufficient strength resulting in awkward postures	7	Supervision by Section Commander (reliance on vigilance)	5	245	65
PFMECA. 129	Loss of grip on track links	May result in crush injury when item fall onto personnel	8	Lack of training on proper grip	7	Training is provided to all personnel	1	56	167
PFMECA. 130	Loss of grip on track links	May result in crush injury when item falls onto personnel	8	Not wearing PPE	7	Manual checks prior to work	1	56	167
PFMECA. 131	Loss of grip on track links	May result in crush injury when item falls onto personnel	8	Time constraints leading to rushed actions and not ensuring proper grip	6	Nil	8	384	13

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 132	Loss of grip on track links	May result in crush injury when item falls onto personnel	8	Negligence or overconfidence leading to ETTO	7	Supervision by Section Commander (reliance on vigilance)	5	280	45
PFMECA. 133	Loss of grip on track links	May result in crush injury when item falls onto personnel	8	Fatigue leading to execution error	6	Pre-activity checks Work-rest cycle	6	288	43
PFMECA. 134	Loss of grip on track links	May result in crush injury when item falls onto personnel	8	Repetitive actions leading to ETTO (i.e., taking shortcuts)	7	Supervision by Section Commander (reliance on vigilance)	5	280	45
PFMECA. 135	Loss of grip on track links	May result in crush injury when item falls onto personnel	8	Insufficient strength to maintain grip	7	Supervision by Section Commander (reliance on vigilance)	5	280	45
PFMECA. 136	Failure to lift track links simultaneously	uneven spread of weight may cause personnel to suffer back injuries, or lose grip on the item due to insufficient strength, leading to crush injuries	8	Lack of coordination	8	Supervision by Section Commander (reliance on vigilance)	5	320	41

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 137	Failure to lift track links simultaneously	uneven spread of weight may cause personnel to suffer back injuries, or lose grip on the item due to insufficient strength, leading to crush injuries	8	Miscommunication between team members	5	Feedback by other personnel (depends on vigilance)	5	200	80
PFMECA. 138	Failure to keep the trolley in place while loading	Movement of trolley may cause improper placement of items, or uncontrolled movement of trolley. This may lead to crush injuries when item falls off the trolley, or collision injuries when trolley moves and hits personnel	5	Negligence or overconfidence	7	Supervision by Section Commander (reliance on vigilance)	5	175	92
PFMECA. 139	Failure to keep the trolley in place while loading	Movement of trolley may cause improper placement of items or uncontrolled movement of trolley. This may lead to crush injuries when item falls off the	5	Lack of coordination	8	Supervision by Section Commander (reliance on vigilance)	5	200	80

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		trolley, or collision injuries when trolley moves and hits personnel							
PFMECA. 140	Failure of the trolley wheels due to wear and tear	Jerky movements may lead to inability to control the trolley, resulting in risks of hitting personnel and causing items to fall off. This may lead to hit and/or crush injuries	5	Wear and tear	5	Manual check by crew (Failure cause is easily observable)	3	75	157
PFMECA. 141	Failure of the trolley wheels due to wear and tear	Jerky movements may lead to inability to control the trolley, resulting in risks of hitting personnel and causing items to fall off. This may lead to hit and/or crush injuries	5	Dislodged mounts	4	Manual check by crew (Failure cause is easily observable)	3	60	162
PFMECA. 142	Failure of the trolley wheels due to wear and tear	Jerky movements may lead to inability to control the trolley, resulting in risks of hitting personnel and causing items to fall	5	Overloading	6	Manual check by crew (relies on vigilance)	5	150	100

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		off. This may lead to hit and/or crush injuries							
PFMECA. 143	Failure to control the trolley's momentum due to overconfidence of personnel ability to control trolley and its load	Inability to control the trolley, resulting in risks of hitting personnel and causing items to fall off. This may lead to hit and/or crush injuries	6	Negligence or overconfidence	7	Supervision by Section Commander (reliance on vigilance)	5	210	76
PFMECA. 144	Failure to control the trolley's momentum due to overconfidence of personnel ability to control trolley and its load	Inability to control the trolley, resulting in risks of hitting personnel and causing items to fall off. This may lead to hit and/or crush injuries	6	Insufficient strength due to judgment error in estimating trolley load	7	Supervision by Section Commander (reliance on vigilance)	5	210	76
PFMECA. 145	Failure to control the trolley's momentum due	Inability to control the trolley, resulting in risks of hitting personnel and	6	Lack of coordination	8	Supervision by Section Commander (reliance on	5	240	69

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	to overconfidence of personnel ability to control trolley and its load	causing items to fall off. This may lead to hit and/or crush injuries				vigilance)			
PFMECA. 146	Failure to lift and adjust track shoe alignment in a controlled manner	Lack of control over movement trajectory, leading to impact injuries, or crush injuries	5	Insufficient strength as a result of judgment error	7	Supervision by Section Commander (reliance on vigilance)	5	175	92
PFMECA. 147	Failure to lift and adjust track shoe alignment in a controlled manner	Lack of control over movement trajectory, leading to impact injuries or crush injuries	5	Using too much strength (judgment error) due to inexperience	6	Supervision by Section Commander (reliance on vigilance)	6	180	87
PFMECA. 148	Failure to lift and adjust track shoe alignment in a controlled manner	Uneven spread of weight may cause personnel to suffer back injuries, or lose grip on the item due to insufficient strength, leading to crush injuries	5	Lack of coordination	8	Supervision by Section Commander (reliance on vigilance)	6	240	69
PFMECA. 149	Loosely secured hammer head to shaft	Failure of the hammer due to the head being dislodged from the shaft, as a	8	Loosely secured hammer head to shaft due to wear and tear and/or	2	Manual inspection and double checks but not	4	64	159

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
		result of poor securing		damage		automated			
PFMECA. 150	Loosely secured hammer head to shaft	Failure of the hammer due to the head being dislodged from the shaft, as a result of poor securing	8	Time constraints, leading to skipping the evaluation process	6	Nil	8	384	13
PFMECA. 151	Loosely secured hammer head to shaft	Failure of the hammer due to the head being dislodged from the shaft, as a result of poor securing	8	Overconfidence leading to ignoring observations	3	Nil	8	192	83
PFMECA. 152	Loosely secured hammer head to shaft	Failure of the hammer due to the head being dislodged from the shaft, as a result of poor securing	8	Inexperience leading to failure to carry out evaluation	6	Manual inspection	5	240	69
PFMECA. 153	Failure to hit drift pin with hammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to hammer swing missing the drift pin and hitting somebody.	8	Negligence or overconfidence	4	This type of cause cannot be detected	10	320	41

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 154	Failure to hit drift pin with hammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to hammer swing missing the drift pin and hitting somebody.	8	Repetitive actions leading to loss of concentration	6	Supervision by Section Commander (detection is not readily done)	8	384	13
PFMECA. 155	Failure to hit drift pin with hammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to hammer swing missing the drift pin and hitting somebody.	8	Insufficient training leading to wrong actions	6	Supervision by Section Commander (detection is not readily done)	8	384	13
PFMECA. 156	Failure to hit drift pin with hammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to hammer swing missing the drift pin and hitting somebody.	8	Reduced psychomotor coordination from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest	4	128	118

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
						cycle (instituted process)			
PFMECA. 157	Weakened structural integrity of drive T-bar and/or socket	Failure to loosen bleed valve due to overload failure of Drive T-bar and/or socket	8	Material stress fatigue of Drive T-bar and/or socket	1	Manual inspection by crew (not an included process)	7	56	167
PFMECA. 158	Failure to fit socket fully into the nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard	8	Time constraints leading to rushed actions, causing misalignment errors	6	Manual inspection by crew / section commander (not an included process)	6	288	43

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		impact may cause bruising, cuts, or fractures)							
PFMECA. 159	Failure to fit socket fully into the nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	8	Insufficient training leading to misalignment errors	3	Supervision by Section Commander (detection is not readily done)	8	192	83
PFMECA. 160	Failure to fit socket fully into the nut	Sudden loss of friction cause uncontrolled movement trajectory,	8	Inexperience leading to failure to detect error	6	Nil	8	384	13

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)							
PFMECA. 161	Failure to fit socket fully into the nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or	8	Reduced alertness from insufficient sleep and/or rest leading to execution error	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle	4	128	118

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
		suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)				(instituted process)			
PFMECA. 162	Application of too much force	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	8	Insufficient training	6	Supervision by Section Commander (relies on vigilance)	5	240	69

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 163	Application of too much force	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	8	Time constraints leading to rushed actions	6	Nil	8	384	13
PFMECA. 164	Application of too much force	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the	8	Reduced alertness from insufficient sleep and/or rest	6	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological	4	192	83

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
		failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)				station nowcast Implementation of work-rest cycle (instituted process)			
PFMECA. 165	Mark wrongly	Torquing would be done wrongly	8	Negligence	1	Double checks by Section Commander	5	40	183
PFMECA. 166	Failure to use a calibrated torque wrench	Nut not torqued to specified value	10	Negligence	2	This type of cause cannot be detected	10	200	80
PFMECA. 167	Failure to use a calibrated torque wrench	Nut not torqued to specified value	10	Distractions leading to failure to check	5	Nil	8	400	12
PFMECA. 168	Failure to use a calibrated torque wrench	Nut not torqued to specified value	10	Time constraints leading to omission of checks	6	Nil	8	480	1
PFMECA. 169	Failure to use a calibrated torque wrench	Nut not torqued to specified value	10	Label too hard to read, leading to failure to check	7	Nil	2	140	113
PFMECA. 170	Failure to use a calibrated torque wrench	Nut not torqued to specified value	10	Insufficient training	2	Supervision by Section Commander	8	160	99

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
						(detection is not readily done)			
PFMECA. 171	Failure to gauge the range of motion due to confined workspace (misjudgment)	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Time constraints leading to rushed actions	4	This type of cause cannot be detected	10	280	45
PFMECA. 172	Failure to gauge the range of motion due to confined workspace (misjudgment)	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a	7	Insufficient training causing judgment errors	6	Supervision by Section Commander (detection is not readily done)	8	336	29

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)							
PFMECA. 173	Failure to gauge the range of motion due to confined workspace (misjudgment)	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a personnel is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause his hand to swing and hit the metal tracks or	7	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle (instituted	4	112	123

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)				process)			
PFMECA. 174	Failure to check the correct position	Guide is out of position	5	Insufficient training causing judgment errors	2	Double checks by Section Commander	3	30	188
PFMECA. 175	Failure to insert track pin sufficiently deep to obtain stable and sufficient leverage	Track pin may slip out during lifting process, causing the tracks to fall and hit the personnel, leading to abrasion, bruises, cuts, and/or fractures.	7	Insufficient training leading to judgment errors	6	Supervision by Section Commander (detection is not readily done)	8	336	29
PFMECA. 176	Failure to insert track pin sufficiently deep to obtain stable and sufficient leverage	Track pin may slip out during lifting process, causing the tracks to fall and hit the personnel, leading to abrasion, bruises, cuts, and/or fractures.	7	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast	4	112	123

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
						Implementation of work-rest cycle (instituted process)			
PFMECA. 177	Failure to wait for vehicle to stop engine before commencing task	Uncoordinated movements from the vehicle may cause collision or crush injuries.	9	Miscommunication between team members	2	Feedback by other personnel (depends on vigilance)	5	90	135
PFMECA. 178	Failure to wait for vehicle to stop engine before commencing task	Uncoordinated movements from the vehicle may cause collision or crush injuries.	9	Overconfidence leading to ETTO (skipping steps)	4	This type of cause cannot be detected	10	360	23
PFMECA. 179	Failure to wait for vehicle to stop engine before commencing task	Uncoordinated movements from the vehicle may cause collision or crush injuries.	9	Insufficient training leading to skipping of steps	6	Supervision by Section Commander (detection is not readily done)	8	432	3

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 180	Failure to wait for vehicle to stop engine before commencing task	Uncoordinated movements from the vehicle may cause collision or crush injuries.	9	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle (instituted process)	4	144	102
PFMECA. 181	Failure to secure sufficient leverage for crowbar before lifting the track links	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause the personnel to fall forward and	7	Insufficient strength to maintain leverage	7	Supervision by Section Commander (reliance on vigilance)	5	245	65

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)							
PFMECA. 182	Failure to secure sufficient leverage for crowbar before lifting the track links	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause the personnel to fall forward and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Lack of coordination	8	Supervision by Section Commander (reliance on vigilance)	5	280	45

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 183	Failure to secure sufficient leverage for crowbar before lifting the track links	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause the personnel to fall forward and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Insufficient training	6	Supervision by Section Commander (detection is not readily done)	8	336	29
PFMECA. 184	Failure to secure sufficient leverage for crowbar before lifting the track links	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind	7	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to	4	112	123

Failure Mode ID	**Potential Failure Mode**	**Failure Effects**	**A) Severity (1-10) 10=most severe**	**Potential Causes of Failure**	**B) Occurrence (1-10) 10=most probable**	**Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)**	**C) Detection (1-10) 10=least detectable**	**RPN AxBxC**	**Rank**
		the torque wrench, the failure of the torque wrench may cause the personnel to fall forward and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)				meteorological station nowcast Implementation of work-rest cycle (instituted process)			
PFMECA. 185	Failure to lift and place track on sprocket due to lack of coordination	Personnel may get fingers caught in between the sprocket teeth and the track shoes' slots, resulting in abrasion, bruises, cuts, or crush injuries.	7	Lack of coordination	8	Supervision by Section Commander (reliance on vigilance)	5	280	45
PFMECA. 186	Failure to secure sufficient leverage for crowbar before lifting the track links	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind	7	Lack of coordination (amongst the team propping up the track - which are the personnel holding the crowbar and two	8	Supervision by Section Commander (reliance on vigilance)	5	280	45

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		the torque wrench, the failure of the torque wrench may cause the personnel to fall forward and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)		others at either side of the track to help adjust accordingly)					
PFMECA. 187	Failure to maintain proper leverage due to vehicle moving too fast.	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause the personnel to fall forward and hit the metal tracks or suspension system or chassis of the	7	Lack of coordination (This is a more complex coordination task requiring coordination between the team propping up the track, the ground guides, and the driver)	8	Supervision by Section Commander (reliance on vigilance)	6	336	29

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		vehicle. The hard impact may cause bruising, cuts, or fractures)							
PFMECA. 188	Failure to assemble correctly	Weakened track fixture structure	6	Insufficient experience	2	Double check by section commander	5	60	162
PFMECA. 189	Failure to secure sufficient leverage for crowbar before lifting the track links	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause the personnel to fall forward and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Lack of coordination (amongst the team propping up the track - which are the personnel holding the crowbar and two others at either side of the track to help adjust accordingly)	8	Supervision by Section Commander (reliance on vigilance)	5	280	45

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 190	Failure of track fixture due to worn thread lines resulting in lack of binding force.	Sudden loss of tension may cause the track to snap forward and/or backward in a whiplash fashion, causing blunt force injuries	7	Lack of coordination (This is a more complex coordination task requiring coordination between the team propping up the track, and the ground guides, and the driver)	8	Supervision by Section Commander (reliance on vigilance)	6	336	29
PFMECA. 191	Weakened structural integrity of opened ended wrench	Failure to loosen bleed valve due to overload failure of open ended wrench	7	Material stress fatigue of open ended wrench	1	Manual inspection by crew (not an included process)	7	49	175
PFMECA. 192	Failure to have control over the tightening action due to sudden loss of traction with the track fixture nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the	7	Negligence or overconfidence	4	This type of cause cannot be detected	10	280	45

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)							
PFMECA. 193	Failure to have control over the tightening action due to sudden loss of traction with the track fixture nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Insufficient training	6	Supervision by Section Commander (detection is not readily done)	8	336	29

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 194	Failure to have control over the tightening action due to sudden loss of traction with the track fixture nut	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the wrench, the failure of the wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle (instituted process)	4	112	123
PFMECA. 195	Failure to check the correct gap	Too wide a gap, leading to inability to join track fixtures	2	Insufficient experience	2	Double checks by Section Commander	4	16	191
PFMECA. 196	Failure to insert drift pin sufficiently	Loss of traction during hammering, leading to injuries	6	Negligence or overconfidence	4	Double checks by Section Commander	2	48	179

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA. 197	Failure to maintain control over the pulling action due to sudden loss of proper grip by the crowbar on the track shoe	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause the personnel to fall forward and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Incomplete catch between the crowbar and track shoe leading to disengagement during exertion of force	2	Supervision by Section Commander (detection is not readily done)	8	112	123
PFMECA. 198	Failure to gauge the range of motion due to confined workspace	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind	7	Negligence or overconfidence leading to lack of caution	4	This type of cause cannot be detected	10	280	45

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		the torque wrench, the failure of the torque wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)							
PFMECA. 199	Failure to gauge the range of motion due to confined workspace	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the	7	Insufficient training leading to judgment errors	6	Supervision by Section Commander (detection is not readily done)	8	336	29

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls (Processes to check the cause of failure so that failure mode does not happen)	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
		vehicle. The hard impact may cause bruising, cuts, or fractures)							
PFMECA. 200	Failure to gauge the range of motion due to confined workspace	Sudden loss of friction cause uncontrolled movement trajectory, leading to impact injuries (i.e., if a person is applying a lot of force behind the torque wrench, the failure of the torque wrench may cause his hand to swing and hit the metal tracks or suspension system or chassis of the vehicle. The hard impact may cause bruising, cuts, or fractures)	7	Reduced alertness from insufficient sleep and/or rest	4	Observation of personnel by Section Commander (detection left to chance) Reference to meteorological station nowcast Implementation of work-rest cycle (instituted process)	4	112	123

Similarly, the top risks were consolidated and shown in the next two tables. Table 28 shows the operational activities and their PFMECA.ID, while Table 29 shows the corresponding failure causes and effects.

Table 28. Failure Modes with RPN Greater than 400, with PFMECA.ID

Level 1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	PFMECA.ID
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.168
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.99
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	PFMECA.64
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.102
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.105
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	PFMECA.106
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit Shoe	PFMECA.113
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit Shoe	PFMECA.117
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit Shoe	PFMECA.120
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.8	Hit Shoe	PFMECA.121
8.0	Position Track (Initial)	8.2	Guide track over sprocket	8.2.2	Place track on sprocket	PFMECA.179

Level 1	Operational Activities	Level2	Operational Tasks	Level3	Sub-tasks	PFMECA.ID
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	PFMECA.167

Table 29. Failure Effects and Criticality Analysis of Failure Modes with RPN Greater than 400

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA.168	Failure to use a calibrated torque wrench	Nut not torqued to specified value	10	Time constraints leading to omission of checks	6	Nil	8	480	1
PFMECA.99	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft, as a result of poor securing	9	Time constraints, leading to skipping the evaluation process	7	Supervision by Section Commander (detection is not readily done)	7	441	2
PFMECA.64	Failure of ground guide to provide proper guidance	Ground guides fail to provide correct instructions	9	Wrong interpretation and execution as a result of confusion during coordination from miscommunication	8	Supervision by Section Commander (detection is not readily done)	6	432	3
PFMECA.102	Failure to understand sledgehammer weight characteristics	Strain injuries sustained due to unfamiliarity with sledgehammer	9	Insufficient training leading to perceptual confusions	6	Supervision by Section Commander (detection is not readily done)	8	432	3

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
	and the swinging actions required	weight characteristics and the swinging actions required.							
PFMECA.105	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Insufficient training	6	Supervision by Section Commander (detection is not readily done)	8	432	3
PFMECA.106	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Time constraints leading to rushed actions, causing misalignment errors	6	Nil	8	432	3
PFMECA.113	Loosely secured sledgehammer head to shaft	Failure of the sledgehammer due to the head being dislodged from the shaft, as a result of poor securing	9	Time constraints, leading to skipping the evaluation process	6	Nil	8	432	3

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA.117	Failure to understand sledgehammer weight characteristics and the swinging actions required	Strain injuries sustained due to unfamiliarity with sledgehammer weight characteristics and the swinging actions required.	9	Insufficient training	6	Supervision by Section Commander (detection is not readily done)	8	432	3
PFMECA.120	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Insufficient training	6	Supervision by Section Commander (detection is not readily done)	8	432	3
PFMECA.121	Failure to hit drift pin with sledgehammer due to lack of control (inexperience, overconfidence, insufficient strength)	Crush injuries sustained due to sledgehammer swing missing the drift pin and hitting somebody.	9	Time constraints, leading to misalignment error	6	Nil	8	432	3

Failure Mode ID	Potential Failure Mode	Failure Effects	A) Severity (1-10) 10=most severe	Potential Causes of Failure	B) Occurrence (1-10) 10=most probable	Detection Method/Design Controls	C) Detection (1-10) 10=least detectable	RPN AxBxC	Rank
PFMECA.179	Failure to wait for vehicle to stop engine before commencing task	Uncoordinated movements from the vehicle may cause collision or crush injuries.	9	Insufficient training leading to skipping of steps	6	Supervision by Section Commander (detection is not readily done)	8	432	3
PFMECA.167	Failure to use a calibrated torque wrench	Nut not torqued to specified value	10	Distractions leading to failure to check	5	Nil	8	400	12

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APPENDIX C. HEART TECHNIQUE

A. HEART TECHNIQUE

This section lists the steps and reference tables required to execute the HEART technique. The bulk of this information, including reference tables and formulae, were extracted from NASA's Human Reliability Methods—Selection Guidance for NASA Technical Report published in July 2006 (Chandler et al. 2006).

The HEART technique provides a list of nine generic tasks for the analyst as a reference when assigning basic HEP, as shown in Table 30. Table 30 is coded with task categories in the leftmost column for reference in the subsequent analysis.

Table 30. PSFs used in HEART (Termed as EPC) and the Corresponding "Weight Factors." Adapted from Chandler et al. (2006).

Category of Generic Tasks	**Generic Task**	**Basic HEP**	**5th–95th Percentile**
A	Totally unfamiliar, performed at speed with no real idea of likely consequences	0.35	0.35–0.97
B	Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26	0.14–0.42
C	Complex task requiring high level of comprehension and skill	0.16	0.12–0.28
D	Fairly simple task performed rapidly or given scant attention	0.09	0.06–0.13
E	Routine, highly-practiced, rapid task involving relatively low level of skill	0.02	7E-3–4.5E-2
F	Restore or shift a system to original or new state following procedures, with some checking	3.00E-03	8E-4–7E-3
G	Completely familiar, well-designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards, by highly-motivated, highly-trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids	4.00E-04	8E-5–9E-3
H	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system state	2.00E-05	6E-6–9E-4
I	Miscellaneous task for which no description can be found	3.00E-02	8E-3–0.11

Table 31 shows the list of EPCs and their multiplicative weights to be referenced when modifying the basic HEPs.

Table 31. List of EPC and their Multiplicative Weights. Adapted from Chandler et al. (2006).

	EPC	**Multiplicative weight**
1	Unfamiliarity	17
2	Time Shortage	11
3	Low Signal/Noise ratio	10
4	Features override allowed	9
5	Spatial and functional incompatibility	8
6	Model mismatch	8
7	Irreversibility	8
8	Channel Overload	6
9	Technique unlearning	6
10	Knowledge transfer	5.5
11	Performance ambiguity	5
12	Misperception of risk	4
13	Poor feedback	4
14	Delayed/incomplete feedback	4
15	Inexperienced	3
16	Improvised information	3
17	Inadequate checking	3
18	Objectives conflict	2.5
19	No diversity	2.5
20	Educational mismatch	2
21	Dangerous Incentives	2
22	Lack of exercise	1.8
23	Unreliable instruments	1.5
24	Absolute judgements	1.6
25	Unclear allocation of function	1.6
26	Progress tracking lack	1.4
27	Physical capabilities	1.4
28	Low meaning	1.4
29	Emotional Stress	1.3
30	Ill Health	1.2
31	Low Morale	1.2
32	Inconsistency of display	1.2
33	Poor environment	1.15
34a	Low loading (1st half hour)	1.1

	EPC	Multiplicative weight
34b	Low Loading (each hour)	1.05
35	Sleep cycle disruption	1.1
36	Task pacing	1.06
37	Supernumeraries	1
38	Age	1.02

According to NASA's Human Reliability Methods—Selection Guidance for NASA Technical Report published in July 2006 (Chandler et al. 2006), the steps and formulae to conduct HEP assessment are as follow:

1. For each identified task, match it to the most appropriate category of generic task shown in Table 30. Assign the identified task with the associated basic HEP value. It is important to note that these basic HEP values are only applicable when the task is executed under ideal conditions. Therefore, the HEPs are adjusted using steps 2 through 4 for realistic, non-ideal conditions.

2. For each identified task, select and all relevant Error-Producing Conditions (EPCs) and their assigned weights from Table 31.

3. For each identified task, assess the significance of each EPC to the task and assign a value ranging between 0 (best, positive) to 1 (worst, negative).

4. Generated the assessed effect using the following formula:

$$Assessed\ Effect = \{(EPC\ Mulitplier - 1)\ (Assessed\ Proportion\ of\ Effect)\} + 1$$

5. Finally, calculate the final HEP using the equation:

$$Final\ HEP = Basic\ HEP\ x\ \prod_{i=1}^{n} \text{Assessed Effects}$$

B. WORKED HEART ANALYSIS

Table 32 represents a template for the HEART worksheet, developed based on the steps described above:

Table 32. Template Worksheet for HEART Analysis

Process Steps, Names and Description						**Category of Generic Task**	**Generic Task Unreliability (Nominal Unreliability Probability) Refer to Table**	**Error Producing Condition**	**Error Producing Condition (Multiplier) Refer to table**	**Assessed Proportion of Effect (Based on Expert Judgement) Btw 0 to 1 (Does not have to add up to 1)**	**Assessed Effect ((Multiplier-1)(Assessed Proportion of Effect))+1**	**Human Error Probability (Nominal Unreliability Probability x Assessed Effect1 x Assessed Effect 2 …)**	**HEART ID**	**Rank**
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level3**	**Sub-tasks**									

The author worked the HEART analysis and ranked them according to the probability of human error. Table 33 shows the fully worked analysis.

Table 33. Fully Worked HEART Analysis

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	D	0.09	Unfamiliarity	17	0.05	1.8	0.684288	HEART.1	9
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	D	0.09	Time shortage	11	0.1	2			
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	D	0.09	Misperception of risks	4	0.2	1.6			
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	D	0.09	Inexperienced Personnel	3	0.1	1.2			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
1.0	Secure Area	1.1	Identify Area of Operations (AO)	Nil	Nil	D	0.09	Inadequate checking	3	0.05	1.1			
1.0	Secure Area	1.2	Cordon off area	Nil	Nil	E	0.02	Unfamiliarity	17	0.2	4.2	0.145824	HEART.2	24
1.0	Secure Area	1.2	Cordon off area	Nil	Nil	E	0.02	Inexperienced Personnel	3	0.2	1.4			
1.0	Secure Area	1.2	Cordon off area	Nil	Nil	E	0.02	Low meaning	1.4	0.6	1.24			
2.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	E	0.02	Unfamiliarity	17	0.1	2.6	0.389376	HEART.3	15
3.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	E	0.02	Time shortage	11	0.3	4			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
4.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	E	0.02	Inexperienced Personnel	3	0.1	1.2	[redacted]		
5.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	E	0.02	Inadequate checking	3	0.1	1.2	[redacted]		
6.0	Position Vehicle	2.1	Enter Vehicle	2.1.1	Climb onto top of vehicle	E	0.02	Misperception of risks	4	0.1	1.3	[redacted]		
7.0	Position Vehicle	2.1	Enter Vehicle	2.1.2	Open Driver’s hatch	D	0.09	Time shortage	11	0.05	1.5	0.377055	HEART.4	17
8.0	Position Vehicle	2.1	Enter Vehicle	2.1.2	Open Driver’s hatch	D	0.09	Misperception of risks	4	0.3	1.9	[redacted]		
9.0	Position Vehicle	2.1	Enter Vehicle	2.1.2	Open Driver’s hatch	D	0.09	Inadequate checking	3	0.2	1.4	[redacted]		

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
10.0	Position Vehicle	2.1	Enter Vehicle	2.1.2	Open Driver’s hatch	D	0.09	Dangerous incentives	2	0.05	1.05			
11.0	Position Vehicle	2.1	Enter Vehicle	2.1.3	Climb into Driver’s seat	E	0.02	Time shortage	11	0.3	4	0.1344	HEART.5	25
12.0	Position Vehicle	2.1	Enter Vehicle	2.1.4	Climb into Driver’s seat	E	0.02	Inexperienced Personnel	3	0.3	1.6			
14.0	Position Vehicle	2.1	Enter Vehicle	2.1.3	Climb into Driver’s seat	E	0.02	Dangerous incentives	2	0.05	1.05			
2.0	Position Vehicle	2.2	Start Engine	2.2.1	Sound horn	E	0.01	Inexperienced Personnel	3	0.3	1.6	0.0164	HEART.6	35
2.0	Position Vehicle	2.2	Start Engine	2.2.1	Sound horn	E	0.01	Unreliable instruments	1.5	0.05	1.025			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
2.0	Position Vehicle	2.2	Start Engine	2.2.2	Select Gear	E	0.01	Time shortage	3	0.2	1.4	0.02296	HEART.7	34
2.0	Position Vehicle	2.2	Start Engine	2.2.2	Select Gear	E	0.01	Inexperienced Personnel	3	0.3	1.6	[redacted]	[redacted]	[redacted]
2.0	Position Vehicle	2.2	Start Engine	2.2.2	Select Gear	E	0.01	Unreliable instruments	1.5	0.05	1.025	[redacted]	[redacted]	[redacted]
2.0	Position Vehicle	2.2	Start Engine	2.2.3	Press “Start” Button	E	0.01	Unreliable instruments	1.5	0.01	1.005	0.01005	HEART.8	39
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	D	0.12	Unfamiliarity	17	0.05	1.8	0.5926284	HEART.9	12
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	D	0.12	Time shortage	11	0.1	2	[redacted]	[redacted]	[redacted]

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	D	0.12	Inexperienced Personnel	3	0.15	1.3			
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	D	0.12	Dangerous incentives	2	0.05	1.05			
2.0	Position Vehicle	2.2	Start Engine	2.2.4	Check no warning lights	D	0.12	Unreliable instruments	1.5	0.01	1.005			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	E	0.02	Time shortage	11	0.2	3	0.093324	HEART.10	30
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	E	0.02	Inexperienced Personnel	3	0.2	1.4			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	E	0.02	Dangerous incentives	2	0.1	1.1			

Process Steps, Names and Description						**Category of Generic Task**	**Generic Task Unreliability**	**EPC**	**EPC Multiplier**	**Assessed Proportion of Effect**	**Assessed Effect**	**HEP**	**HEART ID**	**Rank**
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.1	Release handbrake	E	0.02	Low loading	1.1	0.1	1.01			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	C	0.16	Time shortage	11	0.2	3	0.912083328	HEART.11	2
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	C	0.16	Misperception of risks	4	0.1	1.3			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	C	0.16	Inexperienced Personnel	3	0.1	1.2			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	C	0.16	Inadequate checking	3	0.1	1.2			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	C	0.16	Unreliable instruments	1.5	0.01	1.005			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.4	Manipulate brake and accelerator pedals	C	0.16	Low loading	1.1	0.1	1.01			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	C	0.16	Time shortage	11	0.2	3	0.9030528	HEART.12	3
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	C	0.16	Misperception of risks	4	0.1	1.3			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	C	0.16	Inexperienced Personnel	3	0.1	1.2			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	C	0.16	Inadequate checking	3	0.1	1.2			
2.0	Position Vehicle	2.3	Drive vehicle into position	2.3.5	Manipulate steering yokes	C	0.16	Unreliable instruments	1.5	0.01	1.005			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
2.0	Position Vehicle	2.5	Stop Engine	2.5.2	Turn off fuel control	E	0.01	Inexperienced Personnel	3	0.3	1.6	0.0164	HEART.13	35
2.0	Position Vehicle	2.5	Stop Engine	2.5.2	Turn off fuel control	E	0.01	Unreliable instruments	1.5	0.05	1.025			
2.0	Position Vehicle	2.5	Stop Engine	2.5.3	Turn off master power switch	E	0.01	Inexperienced Personnel	3	0.3	1.6	0.0164	HEART.14	35
2.0	Position Vehicle	2.5	Stop Engine	2.5.3	Turn off master power switch	E	0.01	Unreliable instruments	1.5	0.05	1.025			
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.1	Climb out of Driver's hatch	E	0.02	Time shortage	11	0.3	4	0.1344	HEART.15	25
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.1	Climb out of Driver's hatch	E	0.02	Inexperienced Personnel	3	0.3	1.6			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.1	Climb out of Driver's hatch	E	0.02	Dangerous incentives	2	0.05	1.05	[redacted]		
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.2	Close Driver's hatch	D	0.09	Time shortage	11	0.05	1.5	0.377055	HEART.16	
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.2	Close Driver's hatch	D	0.09	Misperception of risks	4	0.3	1.9	[redacted]		
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.2	Close Driver's hatch	D	0.09	Inadequate checking	3	0.2	1.4	[redacted]		
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.2	Close Driver's hatch	D	0.09	Dangerous incentives	2	0.05	1.05	[redacted]		
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	E	0.02	Unfamiliarity	17	0.1	2.6	0.389376	HEART.17	

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	E	0.02	Time shortage	11	0.3	4	[redacted]		
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	E	0.02	Inexperienced Personnel	3	0.1	1.2	[redacted]		
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	E	0.02	Inadequate checking	3	0.1	1.2	[redacted]		
2.0	Position Vehicle	2.6	Exit Vehicle	2.6.3	Climb down vehicle	E	0.02	Misperception of risks	4	0.1	1.3	[redacted]		
3.0	Break Track	3.1	Unstow track fixtures & drift pin	3.1.2	Remove track fixtures & drift pin	E	0.01	Inexperienced Personnel	3	0.01	1.02	0.0102	HEART.18	38
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	D	0.10	Unfamiliarity	17	0.01	1.16	0.330930 983	HEART.19	21

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	D	0.10	Time shortage	11	0.1	2	[redacted]		
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	D	0.10	Misperception of risks	4	0.05	1.15			
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	D	0.10	Inexperienced Personnel	3	0.05	1.1			
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	D	0.10	Inadequate checking	3	0.05	1.1			
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	D	0.10	Unreliable instruments	1.5	0.01	1.005			
3.0	Break Track	3.2	Loosen track tension	3.2.1	Loosen bleed valve	D	0.10	Physical capabilities	1.4	0.05	1.02			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
3.0	Break Track	3.2	Loosen track tension	3.2.2	Check tension	E	0.02	Inexperienced Personnel	3	0.01	1.02	0.023664	HEART.20	33
3.0	Break Track	3.2	Loosen track tension	3.2.2	Check tension	E	0.02	Unfamiliarity	17	0.01	1.16	[redacted]		
3.0	Break Track	3.2	Loosen track tension	3.2.4	Clean valve	G	0.0004	Dangerous incentives	2	0.01	1.01	0.00040	HEART.21	46
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	D	0.10	Unfamiliarity	17	0.01	1.16	0.332585638	HEART.22	19
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	D	0.10	Time shortage	11	0.1	2	[redacted]		

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	D	0.10	Misperception of risks	4	0.05	1.15	[redacted]	[redacted]	[redacted]
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	D	0.10	Inexperienced Personnel	3	0.05	1.1	[redacted]	[redacted]	[redacted]
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	D	0.10	Inadequate checking	3	0.05	1.1	[redacted]	[redacted]	[redacted]
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	D	0.10	Unreliable instruments	1.5	0.01	1.005	[redacted]	[redacted]	[redacted]

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	D	0.10	Physical capabilities	1.4	0.05	1.02	[redacted]	[redacted]	[redacted]
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.1	Remove nut from track pin	D	0.10	Low loading	1.1	0.05	1.005	[redacted]	[redacted]	[redacted]
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	D	0.12	Unfamiliarity	17	0.01	1.16	0.921991415	HEART.23	1
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	D	0.12	Time shortage	11	0.3	4	[redacted]	[redacted]	[redacted]

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	D	0.12	Misperception of risks	4	0.05	1.15	[redacted]	[redacted]	[redacted]
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	D	0.12	Inexperienced Personnel	3	0.1	1.2	[redacted]	[redacted]	[redacted]
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	D	0.12	Inadequate checking	3	0.05	1.1	[redacted]	[redacted]	[redacted]
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	D	0.12	Unreliable instruments	1.5	0.01	1.005	[redacted]	[redacted]	[redacted]

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	D	0.12	Physical capabilities	1.4	0.2	1.08	[redacted]		
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.2	Drive track pin partly free	D	0.12	Low loading	1.1	0.05	1.005			
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.3	Remove Drift pin	G	0.0004	Time shortage	11	0.05	1.5	0.0006	HEART.24	43
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.5	Remove Drift pin	G	0.0004	Time shortage	11	0.05	1.5	0.0006	HEART.25	43

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
3.0	Break Track	3.3	Remove track pin (USED track shoes)	3.3.7	Remove Drift pin	G	0.0004	Time shortage	11	0.05	1.5	0.0006	HEART.26	43
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	D	0.12	Unfamiliarity	17	0.001	1.016	0.888269052	HEART.27	5
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	D	0.12	Time shortage	11	0.3	4	[redacted]		
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	D	0.12	Misperception of risks	4	0.05	1.15			
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	D	0.12	Inexperienced Personnel	3	0.05	1.1			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	D	0.12	Inadequate checking	3	0.05	1.1			
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	D	0.12	Impoverished information	3	0.1	1.2			
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	D	0.12	Physical capabilities	1.4	0.2	1.08			
5.0	Dispose old track	5.2	Shift track links	5.2.1	Lift track links	D	0.12	Low loading	1.1	0.1	1.01			
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	D	0.09	Unfamiliarity	17	0.001	1.016	0.669532798	HEART.28	10
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	D	0.09	Time shortage	11	0.3	4			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operatio nal Tasks**	**Level 3**	**Sub-tasks**									
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	D	0.09	Misperception of risks	4	0.05	1.15	[redacted]	[redacted]	[redacted]
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	D	0.09	Inexperienced Personnel	3	0.05	1.1	[redacted]	[redacted]	[redacted]
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	D	0.09	Inadequate checking	3	0.05	1.1	[redacted]	[redacted]	[redacted]
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	D	0.09	Impoverished information	3	0.1	1.2	[redacted]	[redacted]	[redacted]
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	D	0.09	Unreliable instruments	1.5	0.01	1.005	[redacted]	[redacted]	[redacted]
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	D	0.09	Physical capabilities	1.4	0.2	1.08	[redacted]	[redacted]	[redacted]

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
5.0	Dispose old track	5.2	Shift track links	5.2.3	Push trolley to work area	D	0.09	Low loading	1.1	0.1	1.01	[redacted]		
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	D	0.12	Unfamiliarity	17	0.001	1.016	0.892710397	HEART.29	4
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	D	0.12	Time shortage	11	0.3	4	[redacted]		
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	D	0.12	Misperception of risks	4	0.05	1.15			
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	D	0.12	Inexperienced Personnel	3	0.05	1.1			
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	D	0.12	Inadequate checking	3	0.05	1.1			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	D	0.12	Impoverished information	3	0.1	1.2			
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	D	0.12	Unreliable instruments	1.5	0.01	1.005			
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	D	0.12	Physical capabilities	1.4	0.2	1.08			
6.0	Form Track	6.3	Join track shoes	6.3.1	Join two track links	D	0.12	Low loading	1.1	0.1	1.01			
6.0	Form Track	6.3	Join track shoes	6.3.2	Install Track pin	D	0.09	Unfamiliarity	17	0.001	1.016	0.564860076	HEART.30	13
6.0	Form Track	6.3	Join track shoes	6.3.2	Install Track pin	D	0.09	Time shortage	11	0.3	4			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
6.0	Form Track	6.3	Join track shoes	6.3.2	Install Track pin	D	0.09	Misperception of risks	4	0.04	1.12	[redacted]		
6.0	Form Track	6.3	Join track shoes	6.3.2	Install Track pin	D	0.09	Inexperienced Personnel	3	0.04	1.08			
6.0	Form Track	6.3	Join track shoes	6.3.2	Install Track pin	D	0.09	Inadequate checking	3	0.04	1.08			
6.0	Form Track	6.3	Join track shoes	6.3.2	Install Track pin	D	0.09	Unreliable instruments	1.5	0.01	1.005			
6.0	Form Track	6.3	Join track shoes	6.3.2	Install Track pin	D	0.09	Physical capabilities	1.4	0.01	1.004			
6.0	Form Track	6.3	Join track shoes	6.3.2	Install Track pin	D	0.09	Low loading	1.1	0.1	1.01			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	D	0.10	Unfamiliarity	17	0.01	1.16	0.332585638	HEART.31	19
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	D	0.10	Time shortage	11	0.1	2	[redacted]		
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	D	0.10	Misperception of risks	4	0.05	1.15			
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	D	0.10	Inexperienced Personnel	3	0.05	1.1			
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	D	0.10	Inadequate checking	3	0.05	1.1			
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	D	0.10	Unreliable instruments	1.5	0.01	1.005			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	D	0.10	Physical capabilities	1.4	0.05	1.02			
6.0	Form Track	6.3	Join track shoes	6.3.3	Install nut on track pin	D	0.10	Low loading	1.1	0.05	1.005			
6.0	Form Track	6.4	Torque nut	6.4.1	Mark nut for torquing	E	0.02	Inexperienced Personnel	3	0.05	1.1	0.0242	HEART.32	32
6.0	Form Track	6.4	Torque nut	6.4.1	Mark nut for torquing	E	0.02	Inadequate checking	3	0.05	1.1			
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	D	0.12	Unfamiliarity	17	0.01	1.16	0.66561264	HEART.33	11
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	D	0.12	Time shortage	11	0.2	3			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	D	0.12	Misperception of risks	4	0.05	1.15			
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	D	0.12	Inexperienced Personnel	3	0.1	1.2			
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	D	0.12	Inadequate checking	3	0.05	1.1			
6.0	Form Track	6.4	Torque nut	6.4.2	Torque nut	D	0.12	Unreliable instruments	1.5	0.1	1.05			
8.0	Position Track (Initial)	8.1	Check track guide position	Nil	Nil	G	0.004	Inexperienced Personnel	3	0.1	1.2	0.00528	HEART.34	41
8.0	Position Track (Initial)	8.1	Check track guide position	Nil	Nil	G	0.004	Inadequate checking	3	0.05	1.1			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.1	Insert track pin	E	0.02	Time shortage	11	0.2	3	0.1034748	HEART.35	27
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.1	Insert track pin	E	0.02	Misperception of risks	4	0.1	1.3	[redacted]	[redacted]	[redacted]
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.1	Insert track pin	E	0.02	Inexperienced Personnel	3	0.1	1.2	[redacted]	[redacted]	[redacted]
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.1	Insert track pin	E	0.02	Inadequate checking	3	0.05	1.1	[redacted]	[redacted]	[redacted]
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.1	Insert track pin	E	0.02	Unreliable instruments	1.5	0.01	1.005	[redacted]	[redacted]	[redacted]
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	D	0.13	Unfamiliarity	17	0.1	2.6	0.887639412	HEART.36	6

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	D	0.13	Time shortage	11	0.1	2	[redacted]	[redacted]	[redacted]
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	D	0.13	Misperception of risks	4	0.01	1.03	[redacted]	[redacted]	[redacted]
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	D	0.13	Inexperienced Personnel	3	0.02	1.04	[redacted]	[redacted]	[redacted]
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	D	0.13	Inadequate checking	3	0.02	1.04	[redacted]	[redacted]	[redacted]
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	D	0.13	Impoverished information	3	0.04	1.08	[redacted]	[redacted]	[redacted]
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	D	0.13	Unreliable instruments	1.5	0.001	1.0005	[redacted]	[redacted]	[redacted]

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	D	0.13	Physical capabilities	1.4	0.2	1.08			
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.2	Place track on sprocket	D	0.13	Low loading	1.1	0.1	1.01			
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	D	0.13	Unfamiliarity	17	0.1	2.6	0.887639412	HEART.37	6
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	D	0.13	Time shortage	11	0.1	2			
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	D	0.13	Misperception of risks	4	0.01	1.03			
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	D	0.13	Inexperienced Personnel	3	0.02	1.04			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	D	0.13	Inadequate checking	3	0.02	1.04	[redacted]		
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	D	0.13	Impoverished information	3	0.04	1.08			
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	D	0.13	Unreliable instruments	1.5	0.001	1.000 5			
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	D	0.13	Physical capabilities	1.4	0.2	1.08			
8.0	Position Track (Initial)	8.2	Guide track over Sprocket	8.2.3	Maintain track propped position	D	0.13	Low loading	1.1	0.1	1.01			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.1	Assemble Track fixtures	Nil	Nil	D	0.09	Unfamiliarity	17	0.001	1.016	0.190268352	HEART.38	22
11.0	Join Track (while on vehicle)	11.1	Assemble Track fixtures	Nil	Nil	D	0.09	Time shortage	11	0.1	2	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.1	Assemble Track fixtures	Nil	Nil	D	0.09	Inexperienced Personnel	3	0.01	1.02	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.1	Assemble Track fixtures	Nil	Nil	D	0.09	Inadequate checking	3	0.01	1.02	[redacted]	[redacted]	[redacted]

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	C	0.16	Unfamiliarity	17	0.05	1.8	0.81563001	HEART.39	8
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	C	0.16	Time shortage	11	0.1	2	[redacted]		
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	C	0.16	Misperception of risks	4	0.01	1.03			
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	C	0.16	Inexperienced Personnel	3	0.04	1.08			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	C	0.16	Inadequate checking	3	0.04	1.08	[redacted]		
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	C	0.16	Impoverished information	3	0.04	1.08			
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	C	0.16	Unreliable instruments	1.5	0.001	1.0005			
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	C	0.16	Physical capabilities	1.4	0.2	1.08			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.1	Move ends of track together	C	0.16	Low loading	1.1	0.1	1.01	[redacted]		
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.2	Install track fixture on outside of track	D	0.09	Impoverished information	3	0.04	1.08	0.0972486	HEART.40	29
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.2	Install track fixture on outside of track	D	0.09	Unreliable instruments	1.5	0.001	1.0005	[redacted]		
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	C	0.16	Unfamiliarity	17	0.001	1.016	0.425862153	HEART.41	14

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	C	0.16	Time shortage	11	0.1	2	[redacted]		
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	C	0.16	Misperception of risks	4	0.01	1.03	[redacted]		
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	C	0.16	Inexperienced Personnel	3	0.04	1.08	[redacted]		
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	C	0.16	Inadequate checking	3	0.04	1.08	[redacted]		

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	C	0.16	Impoverished information	3	0.04	1.08	[redacted]		
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	C	0.16	Unreliable instruments	1.5	0.001	1.0005			
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	C	0.16	Physical capabilities	1.4	0.01	1.004			
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.4	Tighten track fixtures	C	0.16	Low loading	1.1	0.05	1.005			

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.5	Check gap	G	0.004	Inexperienced Personnel	3	0.1	1.2	0.00528	HEART.42	41
11.0	Join Track (while on vehicle)	11.2	Install track fixtures	11.2.5	Check gap	G	0.004	Inadequate checking	3	0.05	1.1	[redacted]		
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	D	0.10	Unfamiliarity	17	0.001	1.016	0.162008297	HEART.43	23
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	D	0.10	Time shortage	11	0.01	1.1	[redacted]		

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	D	0.10	Misperception of risks	4	0.01	1.03	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	D	0.10	Inexperienced Personnel	3	0.04	1.08	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	D	0.10	Inadequate checking	3	0.04	1.08	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	D	0.10	Impoverished information	3	0.1	1.2	[redacted]	[redacted]	[redacted]

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	D	0.10	Unreliable instruments	1.5	0.001	1.0005	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	D	0.10	Physical capabilities	1.4	0.01	1.004	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.1	Align track pin holes	D	0.10	Low loading	1.1	0.01	1.001	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.2	Insert drift pin	E	0.02	Time shortage	11	0.2	3	0.1034748	HEART.44	27

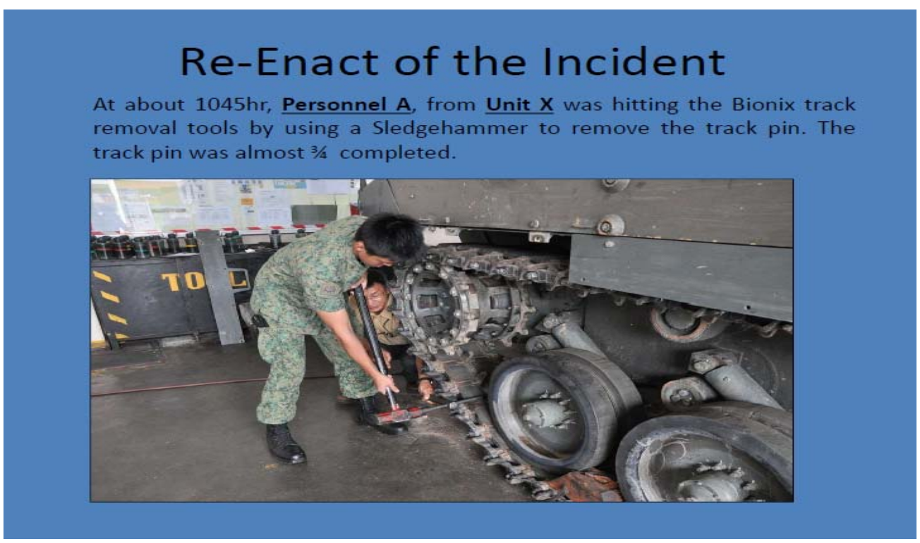
Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.2	Insert drift pin	E	0.02	Misperception of risks	4	0.1	1.3	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.2	Insert drift pin	E	0.02	Inexperienced Personnel	3	0.1	1.2	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.2	Insert drift pin	E	0.02	Inadequate checking	3	0.05	1.1	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.2	Insert drift pin	E	0.02	Unreliable instruments	1.5	0.01	1.005	[redacted]	[redacted]	[redacted]

Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.3	Maintain track pin hole alignment	E	0.02	Impoverished information	3	0.5	2	0.041828904	HEART.45	31
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.3	Maintain track pin hole alignment	E	0.02	Unreliable instruments	1.5	0.001	1.0005	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.3	Maintain track pin hole alignment	E	0.02	Physical capabilities	1.4	0.1	1.04	[redacted]	[redacted]	[redacted]
11.0	Join Track (while on vehicle)	11.3	Join track shoes (while on vehicle)	11.3.3	Maintain track pin hole alignment	E	0.02	Low loading	1.1	0.05	1.005	[redacted]	[redacted]	[redacted]

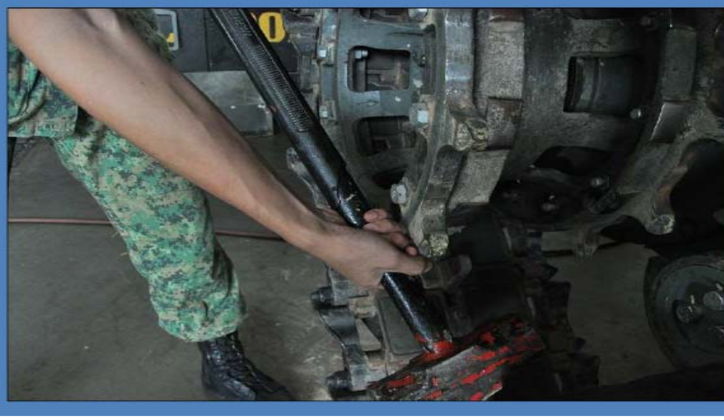
Process Steps, Names and Description						Category of Generic Task	Generic Task Unreliability	EPC	EPC Multiplier	Assessed Proportion of Effect	Assessed Effect	HEP	HEART ID	Rank
Level 1	**Operational Activities**	**Level 2**	**Operational Tasks**	**Level 3**	**Sub-tasks**									
11.0	Join Track (while on vehicle)	11.5	Remove track fixtures	11.5.2	Remove track fixtures	E	0.01	Unreliable instruments	1.5	0.01	1.005	0.01005	HEART.47	39

APPENDIX D. CASE STUDY

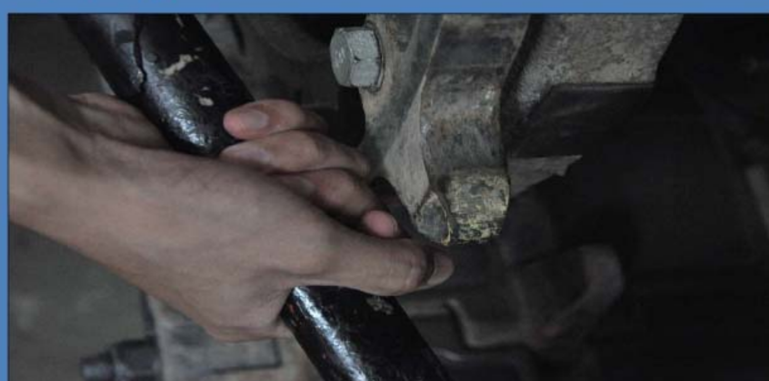
This appendix shows the case study of a workshop incident that took place while the technicians were carrying out the work process of replacing one side of the AFV's track.



At the last stroke of his action, he missed the target and his right hand follow through the momentum and hit the **sprocket teeth with the sledgehammer still in hand**.



Due to his misjudgement actions, he had inadvertently injured his right index **finger partially deformed with broken nail.**



He was still conscious and able to communicate and was send to Medical Centre for treatment and was referred to SGH by Medical Officer.

Events Leading to Injury

Personnel A, from **Unit X** was hitting the Bionix track removal tool by using a Sledgehammer to remove the track pin.

At the last stroke of his action, he missed the target and his right hand follow through the momentum and hit the sprocket teeth with the sledgehammer still in hand.

Due to his misjudgement actions, he had inadvertently injured his right index finger partially deformed with broken nail.

Initial Findings & Causes

Finding & Causes

Personnel A is an experience Senior Tech and more than qualify to handle this task.

He was too eager to expedite this job so as to turn around the vehicle to prepare for LAB inspection.

Recommendation:

If he would have use the personal PPE such as hand glove, the severity of his injury to his index finger would be less severe.

Findings

MAN

a. Proficiency – **Personnel A** is an experience Senior Technician and more than qualify to handle the task.

b. Knowledge – Is competent enough to perform the task.

c. Psychology – Mentally and physically fit.

c. Attitude – Very Professional with exemplary attitude

Findings

(4) If **Personnel A** would have uses the PPE such as his hand glove been provided, the severity of his injury to his right index finger would be less severe.

MISSION

a. Complexity – It is an OM task and mission complexity is assessed as low and **Personnel A** is experience in carrying out the task.

Findings

MANAGEMENT

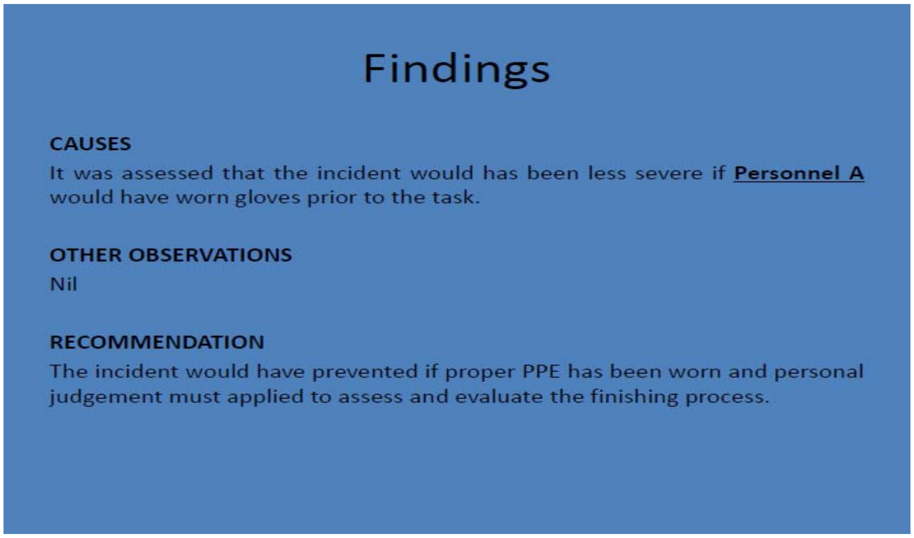
a. Planning and Preparations.

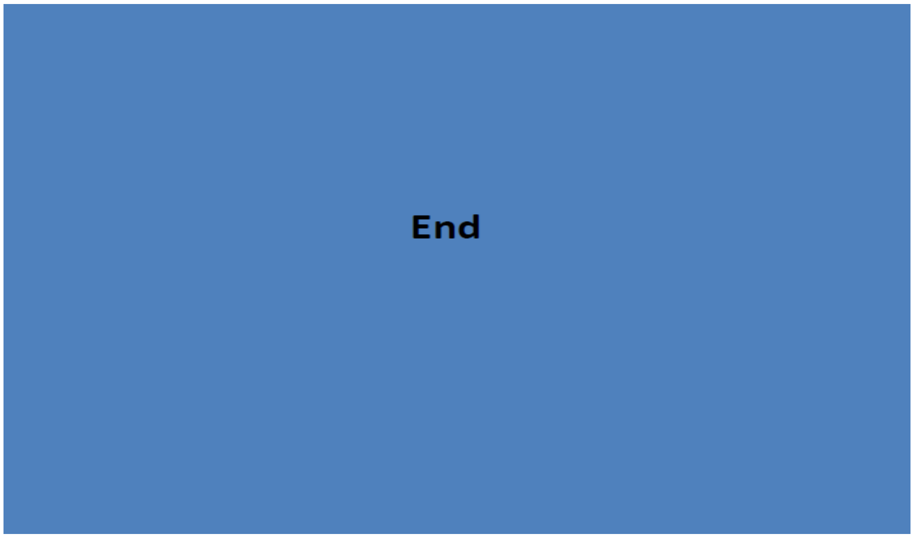
(1) Risk Management – RMP-RAWR is available at the workshop.

(2) Checklist – Checklist is available for the assigned task

(3) Compliance – Task was carried in accordance to BX Operator Manual

MEDIUM – The task was carried out in the workshop and weather and visibility is good.


Findings
CAUSES
It was assessed that the incident would has been less severe if Personnel A would have worn gloves prior to the task.
OTHER OBSERVATIONS
Nil
RECOMMENDATION
The incident would have prevented if proper PPE has been worn and personal judgement must applied to assess and evaluate the finishing process.


End

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